Egleston (Thos.)

THE

PATIO AND CAZO PROCESSES,

FOR

Amalgamating Silver Ores,

BY

THOS. EGLESTON, Ph. D.

[From the Annals of the N. Y. Academy of Sciences, Vol. III, Nos. 1 and 2.]

NEW YORK:
GREGORY BROS., PRINTERS, 34 CARMINE ST.,
1884.

THE

PATIO AND CAZO PROCESSES,

FOR

Amalgamating Silver Ores,

BY

THOS. EGLESTON, Ph. D.

[FROM THE ANNALS OF THE N. Y. ACADEMY OF SCIENCES,
VOL. III, NOS. 1 AND 2.]

NEW YORK:
GREGORY BROS., PRINTERS, 34 CARMINE ST.,
1884.

THE

PATIO AND CAZO PROCESS

OF

Amalgamating Silver Ores.

By THOS. EGLESTON, Ph.D.

The process of amalgamation which is still used both in Mexico and Chili, is called the American method of amalgamation, in order to distinguish it from the process used so long at Freiberg, known as the Freiberg Barrel Amalgamation, and that which has now for so many years been almost exclusively used in the western part of this country, known as Pan Amalgamation. It is effected in two different ways, according to the country in which it is used. In Mexico it is called the Mexican or Patio method, and in Chili it is known as the Chilian or Cazo method. These processes do not differ essentially, except in the mechanical appliances which are used for carrying them on. The Patio method was, until questioned by Dr. Percy,* supposed to have been invented in Mexico, about 1557, for beneficiating the silver ores which occur there.

---

* Percy's Silver and Gold, Part I, p. 562, London, 1880.

The Cazo method was invented in 1609, in Peru,* and has not been used much except in South America and Mexico. The Patio method is used in Mexico on ores that have a mean yield of from thirty to sixty dollars to the ton. Ores of much higher grade than this are treated, provided they are not refractory, but when they are rebellious they are generally treated by fusion. In order to do this, however, the yield must be large, for fuel is very dear on the plains of Mexico.

It is quite rare that anything is done to the ores before treatment, except hand-picking to sort out those of high grade from those of less yield, and to remove some of the sterile material. Occasionally, however, they are treated in a rude way. At Zacatecas† very impure ores are broken by hand into small pieces, made into a pile surrounded by a rude wall laid up dry, and imperfectly roasted with charcoal. In the districts of Tasco and Sultepec, where sulphurous ores are abundant, they are roasted with wood in the same furnace, *comalillos*, in which the magistral is made, but not efficiently, though the operation lasts twelve hours. The *colas*, the concentrated sulphides, are also roasted in piles. This pile-roasting is not only very insufficiently done, but is very uncertain in its results. The object is to remove the substances which attack the mercury, but owing to defects both of fuel and arrangement of the pile, but little results from it, beyond the blind following of a routine which has little other reason than that it has been practised somewhere else. There is always danger that, in roasting these ores, the heat will be raised sufficiently high to melt them. When they are rich, a fusion treatment is much more rational. It is doubtful whether, with a dear fuel, much is gained by roasting previous to the treatment on the *patio*.

It is generally the gangue which determines the name of the ore, but it is sometimes called after its size. Quartz is called *guija*, and quartzose ore *guijoso*; feldspar is called *caliche*; feldspathic ores, *calichoso*. When there is much gangue it is said to be *desploblado*. *Quemazon* is a black porous decomposed ore. Large pieces of the first and second class ores are called *gabarro*. The smalls are called *metal granza*.

---

* Percy's Silver and Gold, Part I, p. 656.

† Phillips's Gold and Silver, p. 352, London, 1867.

The minerals which are usually found as ores, or associated with them, are native silver, *plata;* kerargyrite, *plata cornea blanca;* embolite, *plata cornea verde;* bromyrite, *plata verde;* iodyrite, *plata cornea amarillia;* argentite, *plata negra;* ruby silver, *rosi clara;* arsenopyrite, *ferro blanco;* galena, *plomo;* and zinc blende, *copelilla.*

The ores are generally distinguished as of two kinds, the black, *negros,* and the colored, *colorados.* The former are found in the lower part of veins, and comprise all the ores containing sulphur. The *colorados* are found in the upper parts of veins, and are composed generally of the iodides, bromides and chlorides, with some native silver mixed with them. The gangue is generally oxide of iron, carbonate of lime, or quartz; occasionally some argillaceous schists which, when they are not attacked by the reagents, can be as easily treated as the others. This method is the only one that can be used in many places in Mexico, on account of the high price of fuel.

In some places, the very rich rebellious ore is roasted and then treated, and this should always be done with all the *negros* when fuel is not so dear as to render such a treatment impossible. When the gangue is attacked to any extent this process cannot be used. The works where these operations are carried on are called *haciendas.*

The process consists of five different operations:—

1. Crushing the ore in a Chilian mill, California stamp, or a breaker.
2. Grinding and amalgamating the ore in an arrastra.
3. Treatment on the patio.
    a. Making the *torta.*
    b. Introducing the reagents.
    c. Separating the amalgam.
4. Treatment of the amalgam.
5. Refining the silver.

The following tree, prepared by Mr. R. E. Chism,* gives a very accurate idea of all the details of the process.

* Patio Process, San Dimas, Trans. Am. Min. Engs., Vol. XI, Pl. 1.

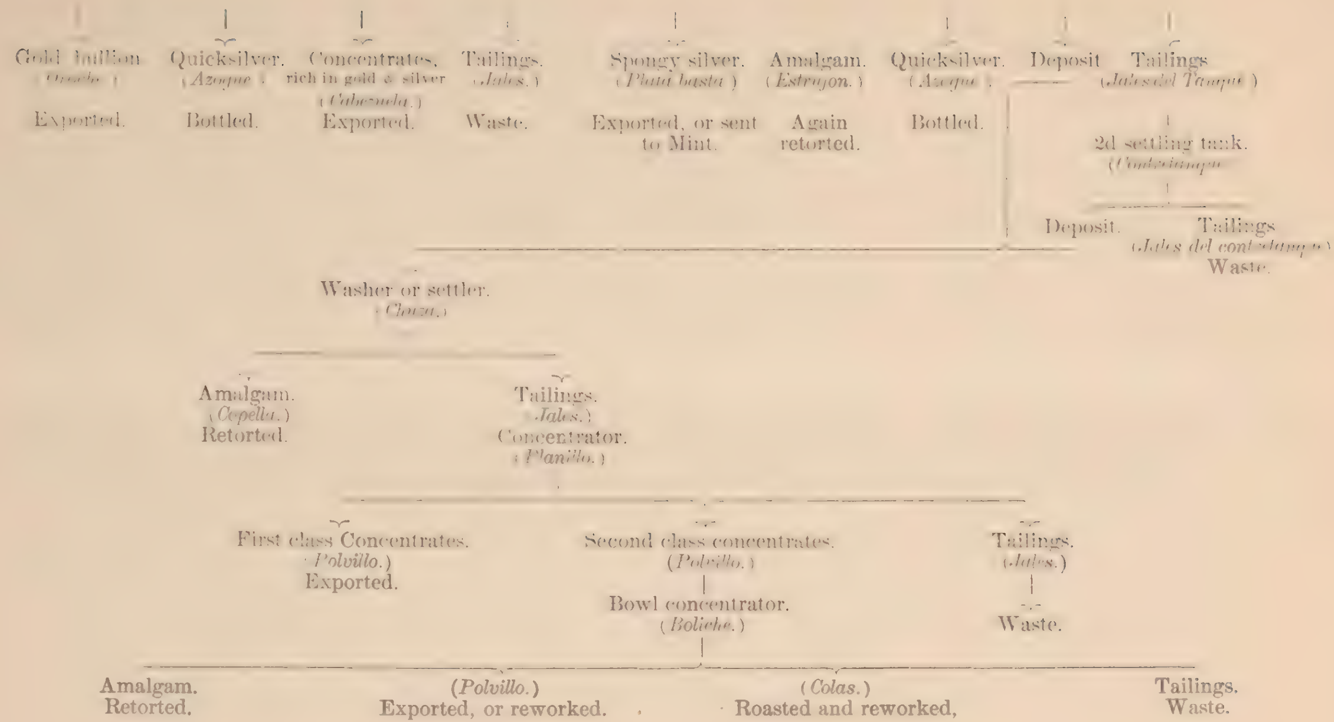
SCHEME OF PATIO PROCESS.

MINE.

- First class ore. (*Metal deExportacion.*) Exported
- Second class ore. (*Metal deBeneficio.*)
  - Breaker. (*Quebradero.*)
- Third class ore. (*Granza de Llunque.*)
- Fourth class ore. (*Tierras de Labor.*)

Arrastra. (*Tahona.*)

- Scrapings. (*Raspadura.*)
  - Washer or settler. (*Chuza.*
    - Amalgam. (*Copella.*)
      - Retort. (*Quemadero.*)
    - Tailings. (*Jales.*)
      - Concentrator. (*Planillo.*)
- Slimes. (*Lama.*)
  - Patio.
    - Washer or settler. (*Lavadero.*)
      - Amalgam. (*Copella.*)
        - Retort. (*Quemadero.*)
      - Tailings. (*Jales.*)
        - Settling tank. (*Tanque.*)


Gold bullion
Exported.
Quicksilver.
(Azoque.)
Bottled.
Concentrates, rich in gold & silver
(Cabezuela.)
Exported.
Tailings.
(Jales.)
Waste.
Spongy silver.
(Plata basta.)
Exported, or sent to Mint.
Amalgam.
(Estrujon.)
Again retorted.
Quicksilver.
Bottled.
Deposit
Tailings
2d settling tank.
Deposit.
Tailings
Waste.
Washer or settler.
(Chuza.)
Amalgam.
(Copella.)
Retorted.
Tailings.
(Jales.)
Concentrator.
(Planillo.)
First class Concentrates.
(Polvillo.)
Exported.
Second class concentrates.
(Polvillo.)
Bowl concentrator.
(Boliche.)
Tailings.
(Jales.)
Waste.
Amalgam.
Retorted.
(Polvillo.)
Exported, or reworked.
(Colas.)
Roasted and reworked,
Tailings.
Waste.

1. Crushing the Ore.

The amalgamating works consist of a large court, *patio*, surrounded by sheds, *galera*, in which the apparatus for comminuting the ores is placed. All of the ore to be treated must be reduced to an impalpable powder. The court is always paved in some way, generally with stones; and if it is desirable that it should contain only a single pile, is only 10 or 15 meters square. When a number of piles are made in the same enclosure, it must be very large, as the piles are often 7 or 8 meters in diameter. The court then would be 50 or 60 meters square, or even larger.

The ores are generally sorted according to their silver contents and gangue, into three or four classes. At San Dimas* there are four grades. The first is the lumps of pure ore picked out by hand, *metal hecho*, or made ore, free from gangue, worth $400 or more to the ton. This is called *metal de primera classe* or *metal de exportacion*. The second is ore for the patio, called *metal de beneficio*. It differs from the first only in being of less value and by having gangue mixed with it. The third class embraces the smalls from the hand-picking, and varies in value according to the value of the ores from which it is selected. It is called *granza de llunque* or *tierras de llunque*. The fourth class comprises the smalls from the mine. It is mixed with much gangue and dirt. It is called *granza de labores* or *tierras de labores*. At Chihuahua,† where the ores are almost entirely composed of native silver in a calcite gangue, they are separated into three classes; the first containing more than $2,500 to the ton; the second, more than $1,000 and less than $2,500; the third class, under $1,000 and averaging about $250.

This classification, however, differs at every works; the first consideration being always the value of the ore; the second, the kind and quantity of gangue, according as it may or may not be attacked by the reagents; and lastly, the size of the pieces.

---

* Patio Process at San Dimas. Trans. Am. Min. Eng., Vol. XI.

† Rept. United States Mining Commissioner, 1874, p. 435.

At Chihuahua the third class ore is carried to the stamps; *morteros*, the best ore, is carried to the store-house, from which it is weighed out. The ore is crushed with small stamps, weighing about 150 kilos each, with a fall of 0.20 m. to 0.25 m. The slots of the screens are 0.15 m. wide. The coarse sand which passes the screens is called *granza*. The lumps of native silver which do not pass through the screens are cleaned by hand. The stamps are run by a horizontal water-wheel. From the stamps the ore is taken to the arrastra. At San Dimas, and generally in the whole country, the ore which is not small enough is broken by hand, until it is small enough to be stamped in old-fashioned German stamps, with wooden stems and iron shoes. Three stamps, weighing 0.50 kil. each, with a drop of 0.22 m., are capable of crushing and forcing out of a screen with 0.15 slots, about 8 tons in 24 hours. These stamp mills, *molinos*, are sometimes run by mule power. In some works rolls are used.

The Chilian mill, *trapiche*, is also still in use. This was formerly a large stone, generally granite, about two meters in diameter, with an edge of 0.40 m. wide, weighing between three and four tons. It was made to revolve on the circumference of an enclosure formerly built up of stones, on a long horizontal arm, which pivoted on a heavy piece of metal driven into a post placed in the centre of the grinding space. When metal was not easily procured, the beam was made to turn on a piece of tough wood. The stone revolved on one end of this beam. The other end projected beyond the outer edge, and to it a horse or mule was attached. The inside diameter of the stone is slightly smaller than the outside, so that it inclines somewhat toward the centre. Sometimes, instead of having one stone only, two stones are placed on the same arm, on opposite sides of the circle, and at different distances from its centre. These wheels run on a bed of hard stone. Sometimes the crushing is done dry; but it is generally done wet—the ground ore being washed out and allowed to settle. The more modern mill* consists of a large wheel, of iron or

* Eng. and Min. Jour., Vol. XXXIII. p. 104.

stone, 1.65 m. in diameter and 0.38 m. wide. It is bound together with an iron tire 0.10 m. thick. It rotates on a horizontal shaft attached to a vertical one. The other end of the shaft projects so that a mule can be harnessed to it. The wheel runs in a circular space made of iron, which is 0.50 m. wide, on the inside of which there is a screen of five or six meshes to the inch. When there are two wheels, the axis is generally about three meters high, and turns on pivots—one fixed in a step raised above the bottom of the grinding-space, and the other held by a frame above. The arm on which the wheels revolve is fixed to this axis, and the power is communicated by an arm fixed above on the axis. This arm may be single for one mule, or may project on both sides; in which case yokes are attached so that a mule can be harnessed at each end. The number of these mills depends on the amount of work to be done. When the amount is small, mules are always used; but when it is large, water power or steam is the motor.

In some of the works both the Chilian mill and the stamps have been abandoned for a series of crushers, *Quebraderos*, or for even a single one. In this way, by a machine readily managed and repaired, a much larger amount of material can be prepared for the arrastra than by either of the other machines.

2. Grinding and Amalgamating the Ore in the Arrastra.

The crushed ore goes from the stamps or Chilian mill to the arrastra, which is a very important part of the process, as the yield of the ore depends very largely on the work which is done in it. Its action is very slow, but no machine yet invented can compete with it in the efficiency of its work. The arrastra is generally circular and somewhat below the level of the ground. It is from 3 to 4 meters in diameter. The bottom is sometimes made of the hardest boulders that can be found in the country, bedded in clay with their smooth sides turned up and ground to something like even surfaces before the operation begins. This is a bad construction, as the open places between

the stones would seem likely to produce a large loss of both mercury and amalgam. It is surprising, however, that with such a rude construction the loss of mercury is not very much larger than in the better-constructed ones. This is owing to the great skill which the men have acquired, not only in working, but in picking out the mercury and amalgam from the cracks, and refilling with slimes. Such an arrastra will have to be run the longest time possible, fifteen or twenty days, before a clean-up is made. It will then generally be found expedient to remove the tailings and work up all the material in the interstices. A properly constructed arrastra can, however, be cleaned up every few days without disturbing the pavement. It is generally built of paving stones or slabs of quartzose porphyry. In the best works, the edges of these stones are carefully dressed and they are put together with cement, or when that cannot be had, with the very fine tails which result from washing up the *torta*. These stones are 0.75 m. in length. They are placed vertically. When put in with care, the bottom will last for twelve months. It will then be necessary to clean out all the cracks and repair it, taking up the stones, carefully scraping them, and washing the dirt upon them and that beneath them, to recover any mercury or amalgam that may have penetrated into the ground. The sides are made generally of flat stones forming a rough curbing 0.60 m. high, which projects enough to make the interior about 0.60 m. deep. In the centre of the arrastra, raised above the bottom, is a pivot hole for the central shaft, which carries four arms, and is supported above and below. To each of these arms one and sometimes two stones are attached, which act as mullers, *voladoras*, to grind the ore. They are made of quartzose porphyry, which must have an open grain so as to present a good grinding surface until it is entirely worn out. A close-grained stone would become smooth after a little wear, and would then be no longer serviceable. They are usually, when there is only one to each arm, a little smaller than the half diameter of the arrastra and about 0.40 m. thick. Two holes are drilled in each one; into these, wooden plugs are driven to receive staples, by which they are fastened to the arms by means of thongs, leather, or chains, in such a way that their front edges will be about 0.05 m. above the bottom, while the rear

drags. When new, all the stones together weigh from 300 to 800 kilos. The arms are sometimes niched so as to allow of changing the position of the stones at will. There are usually four of these mullers, but sometimes only two, and in very rude arrastras only one is used. They do not last much over a month, and are sometimes worn out before that time. When they are worn down to about 200 kilos they are replaced one at a time, so that there are always old and new stones in the mill at the same time.

The arrangement of the arms differs according as animal or water-power is to be used. When mules are used, one of the arms is made to project over the side of the arrastra, and to it one and sometimes two mules are hitched. Such arrastras are called *arrastra de mula*, or when they are of large size, *arrastra de marca.* When water power is to be used, all the horizontal arms project beyond the rim. From these arms rods descend, which support a horizontal wheel, which revolves around outside of the arrastra a few centimeters above the pit. In the circumference of this wheel, at intervals of 0.15 m., rectangular floats, slightly concave, and set edgewise, are placed. These are called spoons, *cucharas*, and these arrastras are distinguished as spoon arrastras, *tahona* or *arrastra de cuchara,* in distinction from the *arrastra de mula.* The men in charge of the grinding are called *tahoneros.* The water strikes these paddles, the power being acquired while descending through a tapering shoot which has a fall of 0.20 m. in every 3.5 m. to 4.5m. This horizontal water-wheel runs in a channel a few centimeters deep on the outside of the arrastra, as shown in the plate.* If the central space, called *tosa*, which is the arrastra proper, is three meters in diameter, it is usually not more, and about 0.50 m. deep, the wheel six meters in diameter with a width of from 0.60 m. to 0.70 m., the outside diameter of the ditch would be about 7 m. Such an arrastra would treat between 400 to 600 kilos of soft ore in twenty-four hours, or if it is hard, 700 and 800 kilos in about three days. This is a wasteful appliance, but there is a superabundance of water, so that it makes little difference. These arrastras are constantly employed when water-power can be

* I am indebted to Dr. Drown, the obliging Secretary of the Am. Inst. of Min. Eng., for the cliches taken from Mr. E. Chism's paper.

had. A wheel of this kind with a diameter of six meters will carry two mullers for 24 hours without stopping, as fast as four mules will, that cannot work for more than eight hours a day. * At Chihuahua such a wheel runs both the arrastra and the stamps. When overshot water-wheels are used, the power is transmitted by spur gearing on the upper part of the central shaft.

In some few cases an overshot water-wheel is used to run a number of arrastras. The power is transmitted by wooden gearings. When the arrastra is new, or when a new bottom has been put in, *rebajado,* it is turned either empty or with a few *cargas* of tailings, *jales*, or low grade ores, *tierras de labor*, so as to make the stones even and fill up the cracks—if the stones have been simply laid together—with material of but little value.

A good deal of importance is attached to the use of the proper quantity of water, and to the times as well as the way in which it is added. When a new bottom has been put in, one muller is attached to the arm, and it is set to work grinding up with water the residues of the washing of a *torta*, to smooth down the pavement and to fill up any cracks. This is continued for one day. The next day another muller is attached; the third day another. On the fourth day poor ores are charged; at the end of four or five days, the fourth muller is attached, and the usual work is then commenced. From one-half to two-thirds of the total quantity of ore to be treated is added at first. If there is any free gold or silver in the ore, a little mercury is added at the start in order to catch it. The quantity of gold contained in most Mexican ores is so small, that if it was not separated in some way in the treatment, it would be absorbed in the silver, and its separation by a parting process would hardly pay, so that it would be lost ; but by adding mercury, especially that which has already been through the arrastra, much of it is collected. When the ores contain a very considerable quantity of native gold or silver, it is desirable to collect as much as possible with mercury in the arrastra; and if no other minerals are associated with it, the whole or the greater part of the treatment, as at Chihuahua, is comprised in its treatment here.

*Report of the U. S. Mining Commission, 1872, p. 436.

The usual charge is one ton; it is often greater in large and less in small arrastras. When the charge has been introduced, a few buckets of water are thrown in to make a sufficiently consistent mud, about half the total quantity used being added at first. If there is too little water, the ore is raised and pushed forward by the mullers without being ground. If there is too much, it packs underneath the mullers. Care is taken to add the water as required, to keep the proper consistence. To do the work most efficiently, the mullers should be made to revolve slowly at first, but when the larger pieces have become reduced, the motion is increased to from six to ten turns a minute. This is sufficiently rapid to prevent the larger and heavier pieces from settling and thus clogging the *voladoras*, and does not make the charge rise over the sides. When the ore has been ground about eight hours, quicksilver is added in sufficient quantities to amalgamate the free gold and silver. The quicksilver is usually amalgamated with either silver, copper or zinc. The quantity added depends on the quantity of gold and silver in the ore, and on the quantity to be worked before a clean-up is made.

When the arrastra is new, or immediately after a clean-up, from two to five kilograms of mercury are added at once. When the work is going on regularly, it is 0.25 kilog. every second day. If there is no free gold or silver, no mercury is added in the arrastra. When 400 kilograms are treated per day, which makes about 12 tons a month, six kilograms of amalgam, containing about 4.5 kilos. of quicksilver, are used. This acts readily as long as there is plenty of free mercury present; but as this becomes saturated with the precious metals, fresh quantities must be added; and to determine what this quantity should be, assays, *tentadura*, of the amalgam taken from the bottom, made by washing in a horn spoon, must be made every day or two. Sometimes the assay is made on a red earthen plate, *platillo*, which is used as a pan.

It is desirable that the amalgam should not be too liquid, for it is then liable to roll into the crevices and be caught there. If, however, it is too dry, the mercury, being already nearly saturated, will not attack the precious metal. A properly constituted amalgam flattens and spreads itself out, and presents large sur-

faces for contact; a liquid one rolls around in globules and may sink into the interstices; and even if it does not, is not so likely to catch the precious metal.

In some places, a quarter of the arrastra* is cleaned to the bottom, and the mixture of ore and amalgam taken out and washed. This, however, is not usually done, except in very small tortas, when the ores being treated are new, or, for some reason, do not work well. Usually the assay is taken by probing in different parts; the different probings being put together and then tested in a small vessel called a *jicara,* by pressing the thumb or finger against the side. With a very little experience the quantity of mercury is quickly arrived at without so large an assay, and the horn-spoon assay is sufficiently exact. When the amalgam is too dry, more mercury must be added. Generally, it is not desirable that the amalgam collected should contain more than 20 per cent. of gold and silver.

The quantity that a single arrastra can grind in 24 hours varies with the hardness and the richness of the ore. It will generally be from 400 to 600 kilos., and will require the use of from 900 to 1200 liters of water. When no grit can be felt between the thumb and forefinger, the work of the arrastra is regarded as complete. When the hands of the men who do the work are not very sensitive, they sometimes make the test by rubbing some of the pulp on the lobe of the ear. There is considerable difference in the fineness of the pulp in different sections. With coarse ore, the amalgamation will not be so perfect; but those who use this practice, claim that the greater yield of fine pulp does not pay the extra expense, and that the economy in production and quicker returns more than pays for the loss in yield. Those who grind fine, maintain the contrary, and claim that their results are satisfactory, in yield, expense and time. Probably the differences in the qualities of the ore have led to the differences in practice in the various districts. When the assay shows that the work is properly done, water is introduced to thin down the mixture and allow the heavier particles to settle. The thin slimes, *lama,* are either dipped out into barrels and carried to the slime-pits, *lameros,* or into launders, from

* Engineering and Mining Journal. Vol. 83. p. 104.

which they run into the settling-vats. Sometimes a spout or plug is put into the sides of the arrastra for the purpose of allowing the pulp to flow into the *launders*. These troughs are removed as soon as they have been used. When the pulp is dipped out, a cover is put on the floor of the arrastra to protect the amalgam. When no protection is used, care is taken not to go near the bottom. The whole of the slimes are not removed at any one time, except to make a clean-up. In the pits, the slimes are allowed to settle until they are ready to be carried to the *patio*. It takes about three days to grind a charge.

At Chihuahua, on native silver ores, the arrastra is generally charged with a ton per day of third-class ore, yielding from $250 to $1,000 per ton, requiring about 25 lbs. of mercury. After three days' run, ore as rich as $2,500 is added, which requires more quicksilver. As much of this ore is added as is necessary for the purpose of getting a suitable amount of amalgam collected in the arrastra, preparatory to the clean-up. Some hours after adding quicksilver, the amalgamator, *azugero*, takes an assay with the horn spoon, washes it, and judges whether the proper amount of quicksilver is present. These assays are regularly made, and by means of them great skill is rapidly acquired in learning how to add the mercury. Every morning, after the silver seems to be amalgamated, a large quantity of water is added to the material in the arrastra, and kept in motion from four to six hours. This separates the amalgam from the fine ore, and allows the heavier particles to settle to the bottom. The fine material which has not been amalgamated runs off, carrying with it all the finely ground ore. The coarse grains, not yet sufficiently reduced, remain and are ground in the next charge. The tails which are thus obtained at Chihuahua are poor, so poor that they are not worth more than $3 a ton for the patio process. They contain all the ores other than silver, except a small part of the ruby and sulphide of silver, which have been reduced at the expense of the mercury. The sulphide of silver, being ductile, is not reduced to powder, but settles to the bottom of the arrastra, and is taken out with the amalgam. Any rich tailings which come from the treatment of rich silver ore which has been

added just before the clean-up, are saved for concentration or treatment.

After a number of charges have been ground, the process of grinding is stopped to allow of collecting the amalgam, which is done by scraping the inside of the arrastra with great care. This operation is called *raspando.* In the most primitive arrastras it is performed as often as twice a month, or perhaps not oftener than twice in three months. In those of the best construction it is done from two to four times a year. As a properly made pavement lasts about a year there is no necessity for doing it oftener. It is done by carefully scraping the stones and the intervals between them with a curved tool, in order to be certain to remove every particle of ore and amalgam; the amalgam so collected is called *raspa* or *raspadura.* In case the pavement is worn out, each stone is carefully scraped and washed, and the earth for a slight depth as well. In some places the *raspa* is simply washed with the addition of fresh mercury in a wooden bowl, *boliche, Fig.* 4, where most of the amalgam is collected. This operation is called *bolichar.* The tails are then washed on the *planillo, Fig.*3, a masonry platform erected for the purpose of concentrating them. The operator here is called the *planillero.* When the ore contains gold, or in the more modern works as at San Dimas, it is washed in a pit called a *chuza, Fig.* 1, which is also used for the treatment of concentrated tails from the *patio.*

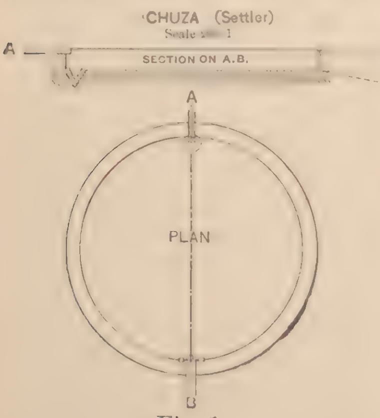


Fig. 1.

The *chuza** is an excavation 3 m. diameter and 0.5 m. deep, lined with cement, with a conical wooden bowl 0.35 m. in diameter. and 0.30 m. deep, whose sides rise 0.05 m. above the cemented bottom on one side. Directly above it at *A, Fig.* 1

* Patio Process at San Dimas.

there is a wooden trough through which water flows freely. At the opposite end there is a trough, *B*, with a gate having three plugged holes through which to let off the slimes. The scrapings are thrown into this trough and are carried by the water into the *boliche;* a boy sitting on the edge of the *chuza* keeps the material in this bowl in constant agitation with his feet. This disintegrates the material. The mercury and amalgam fall into and sink to the bottom of the bowl; the heavy particles other than these are carried into the *chuza*, and the slimes run off by the trough *B*, from which, if of value, they are collected in settling tanks, and if not, run to waste. The tails in the *chuza* are concentrated by drawing out the plugs and letting the lighter material flow away, but the work is done by hand, and yields a very rich material called *cabezuela*, which is sold. When the rich tailings have been separated, the top layer of a coarsely ground ore is removed with iron scrapers and set on one side for the next charge. The amalgam is scraped up and carried in wooden bowls, *bateas*, to the washing-tanks. The gold amalgam collected in the bowl is strained and retorted as the silver is, but not with it. The surplus mercury is not mixed with that from the straining of the amalgam from the patio. It contains considerable gold and silver, and is always used over again to catch the free gold in the arrastra, as amalgamated is always much more lively in catching free gold than pure mercury. The amount of gold separated in this way varies from 30 to 50 per cent. of the total contents of the ore. This gives a bullion that will pay to part. The rest of the gold is recovered in the *patio*, either in the direct washing of the pulp, or in that of the *polvillos*, or is lost in the float during the various processes of washing. When the ore does not contain native silver, 10 to 12 per cent. of precious metals contained are taken from the arrastra. The amalgam taken at the clean-up usually contains from 18 to 22 per cent. of silver.* The coarser the silver is, the less mercury is required.

The loss of mercury in the arrastra is owing to the formation of salts of mercury by the impurities contained in the ores, and

---

* Engineering and Mining Journal, Vol. 33 p. 104 to 114.

also to the flour formed, but more especially to the latter. Phillips gives the following statement of the losses at Guanaxuato,* where the ores contain gold but very little native silver, it being in the form of sulphide:

Composition of amalgam,	Silver,	14 lbs.	
	Mercury,	56 "	
Weight of amalgam used,		70 "	
Mercury added independently of amalgam,			330 lbs.
Mercury in amalgam,			56 "
Gold and silver, *Plata Mixta*, obtained, including that used in amalgam,	Gold,	18 lbs.	84 lbs.
	Silver,	66 "	
			470 lbs.
Amalgam produced,	Gold and silver,	84 lbs.	400 lbs.
	Mercury,	316 "	
Loss,			70 lbs.

As the gold was metallic it probably caused no loss. This loss of mercury is only a little more in weight than the silver contained in the bullion. It is a received opinion among the amalgamators, *azogueros*, that the loss in mercury will always be equal to the weight of silver contained in the ore.

The increase in the non-productive portion of the ore, owing to the constant wearing of the stones of the pavement and the mullers, may be as high as 8 to 10 per cent. It is a great objection to the arrastra, which has therefore been abandoned in all the other processes; but the principle of the machine is a good one, and to this principle we shall undoubtedly have to return. The constant rubbing of the surfaces of the ore by the mullers, and the grinding and constant rubbing in the presence of water, make the metal bright, and the mixing brings it in contact with the mercury. It is a notable fact that in some cases in the early days of California mining, when Mexicans with their rude appliances easily made $50 to $60 a day, the most efficient mod-

* Phillips's Gold and Silver, p. 333. London, 1867.

ern machinery did not extract more than \$15 to \$20. In some instances, with the best modern appliances, an ore yielding by assay \$700 to \$800 did not yield more than \$20 to \$30 when treated in pans, while fully 75 per cent. of its value was recovered by the use of the arrastra. In ores of lower grade, the rapidity of the returns compensated for the loss, but in higher grade ores it did not. It is a matter of great surprise that a machine has not yet been invented to work rapidly on the principle of the arrastra.

3. Treatment on the Patio.

a. Making the Torta.—The process of amalgamating in the arrastra is used when the ore contains considerable quantities of iodides, bromides, chlorides or native silver or gold. When there are none of these minerals present, it is only ground to be subsequently treated on the *patio*, as are also the tails from the treatment of the arrastra. The material from the arrastra is carried to the amalgamation court called the *patio*. This is an enclosure, more or less large, carefully paved and made as impervious to mercury as possible. It is inclined so that water will easily flow from it. Little by little, after several years' use, as the *tortas* are made over the whole surface of the court, the ground will become saturated with mercury. Every two or three years, and oftener if the pavement has to be replaced, and more especially when the *hacienda* has to be abandoned, it will be worth while to clean up and work the dirt beneath the floor. Very many methods have been tried to make and keep this flooring tight. It has been made of artificial stone, of cement, and of asphalt, and, in some places, of cut stone, faced on the edges and made tight with cement. In some places, as in Nevada and also in Mexico, timbers tongued and grooved like mill floors, and covered with water when not in use, have been laid down over an area of an acre and a half. Such a floor as this will last several years. All of these devices are excellent and work well; but as the expense is large, the old method continues in use, and probably will do so till the whole process is abandoned, as it doubtless will be in the course of a few years, when the railroads now being built are completed, and transportation becomes easy and cheap.

The slimes are called *lama;* they are brought to the *patio* as a liquid mud. In order to keep it in the place assigned for the *torta,* in small works a dam of sand or old boards is made to confine it, and it is left for some time exposed to the sun and wind, to hasten the separation of the water by evaporation as well as by drainage. In larger works, the pulp flows from the arrastra into circular walled spaces called *cajetes* or *lameros,* which are used for the same purpose. After sufficient material has been collected to treat it, and when it has acquired the consistence of thick mud, the piles, called *tortas,* or *trillas,* are made. The number and size of these depend on the size of the works. For ore, they vary from 30 to 130 tons each;* for tails, they are usually smaller, or from 16 to 20 tons. They occasionally contain from half a ton to two tons; but such *tortas* indicate working on a very small scale, and the pile is trodden by men. As the material is still too liquid to support itself, a support is made around the outside with beams or stones, the joints between them being made tight with clay. Within this enclosure the pulp is placed. It will usually be about 0.30 m. in thickness. An assay is always taken both to check the work already done by the arrastra and to know what is being done. After several days exposure, the pile will be sufficiently thick to be worked. It is spaded over and made into a regular shape of 7 to 15 meters in diameter.

b. Introducing the Reagents.—In about twenty-four hours after the shaping, from two to five per cent. of salt is scattered over the pile, as evenly as possible. With ores containing from 30 to 35 ounces of silver, four per cent. of salt, with those containing 45 to 75 ounces, about four and a half per cent. is added. The greater the amount of salt, the easier the amalgamation will be, and the more rapidly it will be effected; but notwithstanding the gain in time, it is generally found that the cost of the salt compensates for it, so that the amount is usually restricted to between three and four per cent. The operation of putting in the salt is called *insalmoro.* The salt which is used in the process formerly came

---

* Phillips, p. 343, says that they vary at Guanaxuato from 30 to 80 montones, a montone there being 1.62 tons.

from the evaporation of sea-water; but this was found too expensive, on account of the long transportation. There are in Mexico a large number of salt lakes, called *lagunes*, which dry up every year. The residue contains about 20 per cent. of salt,* and fully 50 per cent. of sand. They also contain both sulphate and carbonate of soda. These impure residues, *saltierra*, are purified to be sent to the works. When purified, they contain from 70 to 90 per cent. of salt—the latter figure being seldom reached—and from 10 to 15 per cent. of carbonate of soda. The impurities make no difference in the reactions, except from there being so much less salt.

The bed of ore which is prepared with salt should be at least from 25 to 30 centimetres in thickness, depending somewhat on the consistence of the pulp. The thinner the pulp, the thicker the bed may be. In order to make the pile as homogeneous as possible, it is trodden by mules or horses—8 to 25 being required for treading a pile—the latter number being necessary for a 100 ton *torta;* 16 mules and 8 men are required for a 60 ton *torta.*† The thickness and consistence of the ore should be such that they can tread it without too much difficulty, as the work is extremely laborious. In order to have a perfectly uniform action, the slimes should not be too thick—the thickness being settled by the hoof of a mule being able to penetrate to the bottom, and to be withdrawn without difficulty—leaving a hole which does not close up for several seconds.‡ Whenever the mules stop for rest, the spading is continued. In this way the salt is thoroughly incorporated through the whole mass. This operation of treading is called *repaso*. During this time no chemical action takes place, but only a mixture of the ore and salt has been accomplished. Every possible effort has been made to do away with this treading, as it is so fatiguing to the animals, and if not well done does not allow of a full treatment of the ore. Mechanical devices of many kinds have been invented with more or less success. Weighted wheels,§ moved in various ways by mechanical devices, more or less complicated, have been

* Laur, Metallurgie de l'Argent au Mexique; Annales des Mines, Series 6, Vol. 20, p. 65. † *Ibid.* p. 144. ‡ *Ibid.* p. 141.

§ Percy's Silver and Gold. Part I, pp. 611 and 613,

tried with what seemed to be, in many cases, great success for a time; but the cost of repairs has eventually caused the return to the old way of treading with mules, which will probably be used until the process disappears. The pile is trodden and spaded during the day. The next morning it is again trodden by the mules for an hour or two, and spaded again; after which, the "*magistral*" is added. This substance was formerly a mixture of the sulphates of copper and iron, obtained exclusively by roasting iron pyrites in double-hearthed furnaces called *comalillos.* It contains some gangue, but this does not affect the treatment. The substance, however, is not of equal composition, as it is obtained by roasting copper pyrites of very variable yield. The following analyses of this *magistral* show how it may vary.

Soluble in Water.	Poor.*	Best.†	*Insoluble in Water.*	Poor.	Best.
Water, - - -	7.60	14.84	Oxide of copper, -	5.70	0.62
Oxide of copper, -	2.50	6.44	Oxide of iron, - -	20.50	23.20
Oxide of iron, -	0.57	0.20	Oxide of lead, - -	0.00	7.35
Lime, - - -	3.17	0.00	Lime, - - -	7.84	0.00
Soda, - - -	1.47	4.19	Silica, - - -	38.00	28.82
Sulphuric acid, -	9.15	9.61	Sulphur, - -	2.22	2.80
Chlorine, - - -	0.12	2.47	Insoluble,	74.26	62.79
			Soluble,	24.58	37.75
	24.58	37.75		98.84	100.54

	Poor.	Best.
Sulphate of Copper, - - - - -	9.03	19.00
Oxide of Copper, - - - - -	5.00	5.50
Sulphate of Iron, - - - - -	6.75	14.80
Sesquioxide of Iron, - - - -	18.75	25.80
Insoluble, - - - - - -	60.47	34.90
	100.00	100.00

In Peru,‡ an ore of copper which contains as high as 13.62 per cent. of sulphate of copper, already an excellent magistral, is used for making it. This is roasted with salt, and when finished and ready to be used, contains about half the soluble

* Annales des Mines, 6th Series, Vol. 20, pp. 75, 76.
† Berg und Hüttenmännische Zeitung, 1881, p. 302. ‡ *Ibid.*

sulphate that it did before. This is owing to the fact that the tradition has indicated that the ore must be roasted with salt, which in this case, at least, is not only useless, but is a harmful condition. When copper ores containing sulphur are not found, but other copper ores are, these are roasted with the addition of iron pyrites for the purpose of making the sulphate of copper. When there are no ores of copper, roasted iron pyrites alone is sometimes used.* Laur cites the following experiments :—

Two *tortas* of ores easily amalgamated were made and treated in exactly the same way, and at the same time. The piles were composed as given below :—

	Sulphate of Copper. Torta.	Sulphate of Iron. Torta.
Dry Ore, - - -	2,000 kilos.	2,000 kilos.
Salt, - - -	105	105
Sulphate of Copper, -	6	0
" of Iron, - -		6
Mercury, - - -	12	12
Water, - - -	700	700

Each *torta* contained 2,240 grams of silver. After 18 days, during which time it was necessary to add 16 grams of mercury to each of the piles, each *torta* was washed separately, and the amalgam collected and distilled, with the following result:—

Silver collected in the sulphate of copper torta, - -	1,890 grams.
" " " iron torta - -	780 "
Loss in silver in the sulphate of copper torta, - -	15.6 per cent.
" " " iron torta - - -	65 "

This explains sufficiently well why sulphate of copper is preferred, although the losses in such experiments, made in a very small way, are much more than they would be in a large *torta*. But even supposing that the loss is reduced to ten per cent., with sulphate of copper used in a large way, the loss by the use of sulphate of iron would still be 41.6 per cent.

In Chili and Peru,† considerable quantities of sulphate of

* Annales des Mines, 6th Series, Vol. 20, p. 262.

† Berg und Hüttenmännische Zeitung, 1881, p. 302.

iron are found. It is mixed with insoluble copper ores in order to produce the necessary soluble copper salts.

$$Fe_2\,3\,SO_4 + 3\,Cu\,O = 3\,Cu\,SO_4, + Fe_2\,O_3.$$

The iron is precipitated and the sulphate of copper crystalized. The same result is obtained with malachite. Chloride of iron may also be used to produce chloride of copper.

$$Fe_2\,Cl_6 + 3\,Cu\,O = 3\,Cu\,Cl_2 + Fe_2\,O_3.$$

With atacamite, a mineral frequently found in these countries, a mixture of chloride and sulphate of copper is formed.

$$Cu\,Cl_2,\,3\,Cu\,O + Fe_2\,3\,SO_4 = Cu\,Cl_2 + 3\,Cu\,SO_4, + Fe_2\,O_3.$$

With chloride of iron—

$$Cu\,Cl_2,\,3\,Cu\,O + Fe_2\,Cl_6 = 4\,Cu\,Cl_2 + Fe_2\,O_3.$$

Decomposing iron pyrites can also be used—

$$2\,Fe\,SO_4 + 2\,Cu\,O + O = 2\,Cu\,SO_4 + Fe_2\,O_3.$$

This last reaction is a little slow; but if roasted pyrites is used, it takes place very quickly. If a little excess of the oxide of copper is added, no iron is left in solution. The mixture should be roasted in such a way as not to decompose any of the sulphate of copper, but all the sulphate of iron should yield its sulphuric acid to the oxide of copper; this it is almost impossible to do. But the heat makes rapid action possible.

When no sulphate of iron can be had, as in some parts of Peru, sulphate of alumina can be used:

$$Al_2\,3\,SO_4 + 3\,Cu\,O = 3\,Cu\,SO_4 + Al_2\,O_3.$$

The decomposition does not take place so rapidly or so completely as with the sulphate of iron, owing to the pasty condition of the alumina produced.

On account of the difficulty of obtaining the magistral, whose only efficiency is the amount of sulphate of copper that it contains, of the same strength at different times, sulphate of copper has been entirely substituted as magistral in many places for the roasted copper pyrites magistral, with great success and greater certainty and celerity of working; but, in many places, the old magistral is still used, and even when copper pyrites cannot be had, roasted iron pyrites is used.

The magistral is the most important reagent employed, and at the same time the cheapest. A little salt, more or less, makes no special difference; but an excess of magistral is always disastrous, and its effects must be attended to at once, or they will cause a serious loss of both mercury and silver. The operation of adding the magistral is called *incorporo.* Whatever magistral is used, it is scattered evenly over the surface with wooden shovels, and then thoroughly incorporated through the pile by digging it in—the operation being called *voltear la torta,* or turning the pile. When this has been done, another *repaso* is made. which is repeated every second or third day for about eight hours. The quantity of magistral added varies from one half to two per cent., according to the nature of the ore and the quantity of sulphate of copper contained in it; more being required as there are more sulphides. On the supposition that the sulphate of copper alone is of use, about five pounds to the ton of a 35 to 60 ounce ore is required. Generally from six to eight kilos of mercury, *azogue,* is added for every kilo. of silver contained in the ore in the *torta,* as determined by the fire assay. The amount of mercury put in at this time varies with the theory of the amalgamator. Some add two-thirds; others three-fourths of the lowest quantity at once; others add it in very small quantity at first, and the rest gradually. In any case, the effort is made to add it in the smallest globules possible, by walking over the pile and squeezing the mercury through a canvas bag containing not more than five or six kilograms of it, or through strainers, so as to distribute it as evenly as possible over the pile.

Immediately after the addition of the quicksilver, the animals are set to treading, the spading being done when they rest. This is continued for two hours. A solution of hot sulphate of copper is then added to the pile; the quantity being larger as the ore contains sulphur, arsenic, antimony or zinc. For ordinary pure sulphurets, about four kilograms to the ton are used. Precipitated copper, *precipitado,* in the proportion of one part of copper to five of sulphate, is also used. This cools the pile. After the sulphate is added, the *torta* is trodden again until 3 P. M. The mules employed for this purpose do no other work. They are generally blindfolded, and are driven

in teams of not more than eight or nine. They are usually tied together four abreast, and are driven by a man who stands in the centre of the *torta* holding the halter, and who, by the aid of a long whip, makes them walk in such a way, commencing at the outer edge, as to cover every part of the *torta*. Sometimes two teams are at work on the same *torta* when it is very large. A day's work is from 6 A. M. to 3 P. M. It is very fatigueing. When the work of treading stops, the feet of the mules are carefully washed in a tank provided especially for that purpose, not only to recover the rich material, but also to keep the mules healthy; otherwise, being in constant contact with so much mercury, they would soon become diseased. They cannot be prevented from licking themselves, however, to get the salt the mud contains. Balls of amalgam, which often weigh* from 50 to 100 grams, are sometimes found in their stomachs; which, however, contain but little mercury.

The reactions in the *torta* commence at once after the magistral is added. It is said to work cold or hot. There are two kinds of heat: the first is due to an excess of the reagents; the second results from cold, and is called *calor de frio*. They differ as to their cause, but the result is the same, and increases the loss in mercury while it diminishes the extraction of the silver. On cold mornings, the heat of the pile being greater than that of the air, the pile steams; but as the sun rises higher this vapor ceases. This is called the *calor de frio*. When there is an excess of magistral, the chloride of mercury acts on the sulphide of silver and makes chloride of silver and sulphide of mercury—which latter is entirely lost. A large amount of heat is produced in this way. When the heat is thus caused by the excess of the reagent, wood-ashes or lime is added to decompose the chloride of copper which is formed. Lime or ashes are, however, never added when it can be avoided; they do not revivify the mercury, and they retard the operation and diminish the yield of both gold and silver. When lime is used, it should be in fine powder, and only just enough should be added to produce the effect. If large pieces of it were used, they would not be likely to be wholly acted on by the time the *torta* was right again, and their effect would have to be counteracted, as the

* Phillip's Gold and Silver, p. 341.

pile would become too cold. Tails, or any other sand free from soluble substances, can be used; but these are open to the objection that they increase the bulk without increasing the yield of the *torta*. When the heat is not too great, it can sometimes be cured by the application of cold water; but care must be taken not to add so much as to thin the pulp. Cold working means simply that the operation does not proceed quickly enough, and that an insufficient quantity of magistral has been added to the pile. If left in this state, a large quantity of mercury would be lost as oxide of mercury. To ascertain exactly what is to be done with the *torta* when in this state, assays of from 1 to 3 kilos., *ijadas*, are taken, and what is required added according to the indications which they give.

Many amalgamators prefer to work the *torta* rather hot. When it is manifestly too hot, they allow it to remain perfectly idle for a few days, taking assays all the time to ascertain when it gets back to the proper condition. They add nothing to the pile in the meantime, and when it has come back to its normal condition, go on as if nothing had happened. They think that they gain time and do not lose any more quicksilver than if they worked faster, and that they get a larger yield of the precious metals. In the winter season a little less sulphate of copper is required than during the summer. They generally begin to diminish the quantity of the reagent in September.

There have been a great many theories in regard to the action of these reagents, and a great many investigations of them, which can hardly be said to have cleared up many of the obscure points. A resumé of what has been done is given below, which, however, is not very satisfactory, and does not throw much light on the subject. Some of the published reactions, after careful trial, could not be obtained. The reactions given below have been compiled in the hope that some one may be led to make a more careful examination of the whole subject.

The amalgamators suppose that the chloride of sodium cleans the silver and the sulphate of copper heats it, and that the amalgam of silver and mercury results. The mercury lost is counted as lost mechanically; the amount of loss being about equal in weight to that of the silver extracted.

The generally received theory is, that the salt and the sulphate

of copper act, the one on the other, and give rise to chloride of copper and sulphate of soda :*

$$CuSO_4 + 2\ Na\ Cl = Cu\ Cl_2 + Na_2SO_4.$$

The chloride of copper acts on the metallic silver and the sulphide of silver; chlorides of silver are formed, which are dissolved in the excess of chloride of sodium.

$$2\ Ag + 2\ Cu\ Cl_2 = 2\ Ag\ Cl + Cu_2\ Cl_2.$$
$$Ag_2\ S + Cu\ Cl_2 = 2\ Ag\ Cl + Cu\ S.$$

When mercury acts on artificially prepared chloride of silver, it reduces it to a metallic state, when it enters into combination with the mercury.

$$2\ Ag\ Cl + 2\ Hg = Hg\ Cl_2 + Ag_2\ Hg.$$

This reaction takes some time, and is less sensible on the natural than on the artificial substance.

If chloride of copper is treated with mercury, sub-chloride of copper and sub-chloride of mercury are formed.

$$2\ Cu\ Cl_2 + 2\ Hg = Cu_2\ Cl_2 + Hg_2\ Cl_2.$$

This reaction takes place more rapidly than with chloride of silver. If chloride of iron is substituted for the chloride of copper, all the reactions take place, but much more slowly, and this is especially true when sulphide of silver is present. The presence of salt accelerates the reactions in all cases. If any of the metallic silver in the ore has not been transformed into chloride, this is attacked directly by the mercury.

When sulphide of silver and mercury are shaken together, sulphide of mercury and amalgam are formed.

$$Ag_2\ S + 2\ Hg = Ag_2\ Hg + Hg\ S.$$

This reaction is slow but much quicker than with chloride of silver. All the sulphide of mercury is entirely lost.

Rammelsberg and Huntington have recently made the following investigations:† If sulphide of silver and chloride of copper are made to act on each other, either sub-chloride of cop-

* Berg und Hüttenmännische Zeitung, 1881, p. 303.

† Die Metallurgie des Silbers und Goldes, von J. Percy, p. 12, Brunswick, 1881, and Min. Eng. Journal, Vol. 34, p. 150.

per, chloride of silver and sulphur are produced, or the sub-chloride of copper formed becomes a sulphide.

$$Ag_2\,S + 2\,Cu\,Cl_2 = 2\,Ag\,Cl + Cu_2\,Cl_2 + S.$$
$$Ag_2\,S + Cu_2\,Cl_2 = 2\,Ag\,Cl + Cu_2\,S.$$

The liberation of the sulphur is, however, a secondary reaction, taking place only to a very limited extent, thus:

$$Ag_2\,S + Cu\,Cl_2 = 2\,Ag\,Cl + Cu\,S$$
$$Cu\,S + Cu\,Cl_2 = Cu_2\,Cl_2 + S.$$

When the solution is boiled for some time, the sulphur disappears and sulphuric acid is formed. The amount of sub-chloride formed, and of sulphur set free, is dependent on the strength of the solvent, which in this case is salt, on the temperature, and on the presence of air. The secondary reaction depends on the power of the solution to dissolve the chloride. If this could be removed, the solvent power of the solution would be to a certain extent regained. The action of the air in facilitating the secondary reaction is due to its converting the sub-chloride into an insoluble oxy-chloride.

$$3\,Cu_2Cl_2 + 3\,H_2O + 3\,O = 3\,CuO,\ Cu\,Cl_2,\ 3\,H_2O + 2\,Cu\,Cl_2.$$

If chloride of copper and sulphide of silver are boiled together the decomposition is complete.

$$Ag_2\,S + Cu\,Cl_2 = 2\,Ag\,Cl + Cu\,S.$$

When sub-chloride of copper and sulphide of silver are mixed, the following reaction takes place:

$$Ag_2\,S + Cu_2\,Cl_2 = 2\,Ag\,Cl + Cu_2\,S.$$

When one hundred parts of the sulphide of silver were treated with sub-chloride, in a solution of salt, as much as 7.6 or 8.3 per cent. of the silver remains dissolved in the salt solution. When the residue was treated with zinc, the following reaction took place :—

$$Ag_2\,S + Cu_2\,Cl_2 + Zn = Zn\,Cl_2 + Cu_2\,S + 2\,Ag.$$

When a salted solution of sub-chloride of copper is mixed with a saturated solution of chloride of silver in salt, no precipitation takes place, nor can it reduce chloride of silver when it is in powder. If sulphide of silver is added to the salt solution of sub-

chloride of copper, chloride of copper, sulphide of copper, and metallic silver are produced.

$$Na\,Cl, Cu_2\,Cl_2 + Ag_2\,S = Na\,Cl, Cu\,Cl_2 + Cu\,S + 2\,Ag.$$

It thus appears, that while it cannot affect the chloride of silver, the sub-chloride of copper can reduce sulphide of silver, which, in the presence of mercury, is amalgamated without having passed into the state of chloride at all. If ammonia is added to the solution of the sub-chloride of copper and chloride of silver, silver is precipitated.

$$2\,Ag\,Cl + Cu_2\,Cl_2 + N\,H_3 = 2\,Ag + 2\,Cu\,Cl_2 + N\,H_3.$$

When chloride of silver, sulphide of copper, and ammonia are heated, a blue solution is obtained. One half the chloride of silver is converted into sulphide of silver. The residue, which is black, is composed of sulphide and chloride of silver, and contains no copper.

$$8\,Ag\,Cl + 2\,Cu\,S = \underbrace{Ag\,Cl + 2\,Ag_2\,S}_{\textit{Not Dissolved.}} + \underbrace{3\,Ag\,Cl + 2\,Cu\,Cl_2}_{\textit{Dissolved.}}.$$

Three parts of chloride of silver and two of chloride of copper remain in solution.

If two parts of chloride of silver dissolved in ammonia are treated with sub-sulphide of copper, a mixture of silver and sulphide of copper is precipitated, about one tenth of the silver still remaining in solution.

$$2\,Ag\,Cl + Cu_2\,S = 2\,Ag + Cu\,S + Cu\,Cl_2.$$

If four parts of chloride of silver are used, the copper remains almost entirely in solution, and 28.2 parts of the silver are also in solution. The residue consists of metallic silver and sulphide of silver.

$$4\,Ag\,Cl + Cu_2\,S = 2\,Ag + Ag_2\,S + 2\,Cu\,Cl_2.$$

Prof. Huntington found, that when chloride of silver and sulphide of copper are mixed in an ammoniacal solution, sub-chloride of copper is formed, which reacting on the chloride of silver forms metallic silver and chloride of copper.

$$2\,Ag\,Cl + Cu_2\,S + NH_3 = Ag_2\,S + Cu_2\,Cl_2\,N\,H_3.$$
$$2\,Ag\,Cl + Cu_2\,Cl_2\,NH_3 = 2\,Ag + 2\,Cu\,Cl_2\,N\,H_3.$$

The chloride solution for this reaction must be kept at a certain strength or the reaction will cease, and anything which causes further dilution will undo a part of the work already accomplished.

When chloride of copper and sulphide of arsenic are mixed, rapid decomposition takes place, and a precipitate of sulphide of copper and chloride of arsenic is formed.

$$As_2 S_3 + 3\ Cu\ Cl_2 = 3\ Cu\ S + 2\ As\ Cl_3.$$

When chloride of copper and sulphide of antimony are mixed, a precipitate containing sulphur, copper, oxygen, chlorine and antimony is formed. Some antimony remains in solution on account of the sulphuric acid formed. When sub-chloride of copper is used, most of the copper is precipitated in the metallic state.

If proustite and pyrargyrite are treated with chloride of copper both are decomposed. All the silver of the pyrargyrite is converted into chloride, while only a part of that in the proustite is so acted on The reaction for proustite is

$$4\ Ag_3\ As\ S_3 + 12\ Cu\ Cl_2 = 8\ Ag\ Cl + 2\ Ag_2\ S + 2\ Cu\ S + As_2\ S_3 + 5\ Cu_2\ Cl_2 + 2\ As\ Cl_3 + 5\ S.$$

and for pyrargyrite

$$2\ Ag_3\ Sb\ S_3 + 4\ Cu\ Cl_2 = 6\ Ag\ Cl + Cu_2\ Cl_2 + 2\ Cu\ S + Sb_2\ S_3 + S.$$

In both cases, part of the reagents remain in solution.

When sub-chloride of copper is dissolved in salt and boiled with pyrargyrite in powder, a black product is formed which contains most of the silver, all the antimony and sulphur, and some copper and chlorine; 7.3 per cent of the silver is dissolved by the salt.

$$2\ Ag_3\ Sb\ S_3 + Cu_2\ Cl_2 = 2\ Ag\ Cl + Ag_2\ S + 2\ Ag + 2\ CuS + Sb_2\ S_3.$$

When sub chloride of copper and proustite are treated together, a gray product is formed which contains nearly all of the silver and sulphur, two-thirds of the arsenic, and considerable portions of the copper and chlorine.

$$6\ Ag_3\ As\ S_3 + 7\ Cu_2\ Cl_2 = 14\ Ag + 4\ Ag\ Cl + 12\ Cu\ S + 2\ As_2\ S_3 + 2\ Cu\ Cl_2 + 2\ As\ Cl_3.$$

The proportion of the silver dissolved in the salt was 4.7 per cent.

If mercury, sulphide of silver, chloride of sodium, sand and water are worked together, seven-eighths of the silver present is extracted, three times as much as when the salt was not there. If oxide of iron is present in the mixture, chloride of iron will be formed, which is reduced to sub-chloride by the mercury, and a chloride of mercury is formed. A very small amount of oxide of iron produces a very considerable loss, as the sub-chloride constantly changes to chloride of iron, in contact with the air. If to this last mixture sulphate of copper is added, a little less silver is obtained, and the loss of mercury is large. If proustite, which contains 65.5 per cent. of silver, 15.1 of arsenic, and 19.4 of sulphur, is substituted for the sulphide of silver, twice as much silver combines with the mercury when chloride of copper is present. It requires a great deal of shaking to decompose the sulphide of silver. When sulphide of zinc is present with chloride of copper, it causes the formation of sulphide of copper and chloride of zinc, so that ores which contain blende always amalgamate badly.

From these reactions it would seem that, during the first two or three days, chlorides of copper and iron are produced by the action of the magistral on the salt; that chloride of silver is formed by the action of these chlorides on the easily attacked ores, and even on the sulphide of silver; that the chloride of silver is dissolved probably at once in the excess of salt. In chloridizing the silver, the copper and iron salts have become reduced to sub-chlorides, which in the presence of sulphide of silver form the chlorides, and produce metallic silver, or, when it is absent, quickly become oxy-chloride, and produce no further action. Sub chloride of copper reduces sulphide of silver; but the sub-chloride of iron does not. The presence of mercury prevents the formation of an excess of chloride of copper, for as soon as there is an accumulation of it, it acts on the mercury and is reduced to sub-chloride. Just as soon as the mercury is introduced the free silver is amalgamated; the chloride of copper which is still in the pulp forms calomel and sub-chloride of copper, which acts on the sulphide of silver and leaves it as metal, to be acted on by the quicksilver.

Some authors, especially Mr. Bowering, deny that chloride of

silver is formed at all, as none was found in a torta left for four months on the patio, during which time he constantly examined the piles. Mr. Bowering says, in support of this theory, that when only two of the reagents, sulphide of silver, chloride of sodium, or sulphate of copper are mixed together, no effect is produced, and that when three are mixed in a small vessel, the mercury combined with just half of the chlorine in the chloride of copper, and formed sub-chlorides of both metals. As the chloride of copper has the property of absorbing oxygen, he concludes that it is the principal reagent. According to this theory the mercury acting on the chloride of copper makes sub-chlorides of both. The chloride of copper absorbs oxygen, which acts on the sulphide of silver and makes sulphuric acid, and leaves the silver in a metallic state to be absorbed by the mercury. The sulphuric acid set free acts on the chloride of sodium, and forms sulphate of soda. Chlorine is given off, combines with the sub-chloride to make a chloride of copper, which is again decomposed, and so on. In this case the sub-chloride acts just as nitric acid does in the manufacture of sulphuric acid. The action of the chemicals in the pile is especially slow if sulphide of silver is present, in which case the loss of mercury is also very large. When the whole of the silver is in the state of sulphide, a large part of it, which may sometimes be as high as 40 per cent., is lost. The mercury transforms the chloride of copper into sub chloride, which, like chloride of silver, is soluble in an excess of salt. The sub chloride in this state acts more energetically on the sulphide of silver than the chloride. A sulphide of copper is formed, while the silver is precipitated, and the chloride of copper formed again by giving up half the copper, which becomes a sulphide. This advantage is gained only at the expense of a very large quantity of mercury; and in order to prevent this loss, experiments were made of not introducing the mercury until much later in the process, but this did not succeed, as the extraction of the silver was not so well done.

The next day after the first treading, another one is made. The torta is then allowed to rest for a day, with occasional spadings, quite as much to make the mixture as to ascertain whether the ore is not getting too stiff from evaporation. As the heat of the sun is depended on for a part of the chemical action, water, when added,

must be added in the morning, so as not to cool down the *torta* after it has once become heated, and thus disturb the reactions which are taking place. The pile must be trodden several times, the object being to keep renewing the surface of the silver which, without this, would become rapidly covered with a bed of solid amalgam which would prevent further action. The operation lasts from three to six weeks, according to the way in which it is conducted, the temperature of the air and the size of the heap. A succession of cloudy days or cold weather in the summer time will retard the operation. Continued or heavy rains may so thin the pulp as to prevent the reactions taking place, and stop all the working until the pulp thickens up again from evaporation. When all the conditions are the most favorable, the *incorporo* can be completed in 15 to 18 days. When they are unfavorable, it may take from 40 to 50 days. Taking several months together, 20 to 25 days will be the average time. In winter, when the *torta* always works slow, it may last as long as two or three months.

The day after the mercury is added, assays, *tentaduras*, are made, to see how the *torta* is working, to learn if any one of the reagents used is required, or if any of them is in excess. To do this, a probe-sample, which will weigh about 250 grams, is taken from as many different parts of the pile as possible. The assay is washed in a horn spoon or in an earthen plate, *platillo*, 0.18 m. in diameter, and 0.02 m. deep, a rotating motion being given to it. The lighter particles are carried off, and the heavier ones deposited on the bottom in the order of their gravity—the heaviest being in the centre. The mercury which has not yet acted, is generally in the centre, the silver-white amalgam, *ceja*, which, when moved, shows a distinct tail, *lista*, next to this, then the undecomposed black sulphurets, then pyrites, and generally a fifth ring of mercury in flour. Three assays are generally made on the *torta* each day, one in the morning before the work commences, one after the treading is about half done, and a third after it has been completed. During the first few days, the appearance of the mercury remaining unacted upon shows the workman what is taking place. The mercury is always more or less attacked. If during the first day it looks dull, is of a deep gray or lead color, there

is too much magistral, and the *torta* is said to be too hot, and the temperature is really too high. A little lime is then added which decomposes part of the sulphate of copper and slackens the action. Lime is sometimes replaced by alkaline ashes. If on the contrary, the mercury is perfectly brilliant and not acted on at all, or is broken up into little globules, or if it is of a slightly yellow tinge, the *torta* is too cold, and more magistral must be added. It is always better to have too little than too much magistral; more can always be added, but too much means a loss of mercury. When the amalgam, *limadura de plata*, is in the proper condition, it is in thin scales, which are easily collected together into a mass of dry silver amalgam, *pasilla*, and mercury is easily pressed from it with the fingers. When it is very thin, so that it easily breaks up into fine globules, it is said to be *debil*, or weak. When it is hard and crystalline, and so dry that no mercury comes out from it when it is pressed, the amalgam is said to be strong, *fuerte*, and more mercury must be added. A dirty blackish appearance to either the mercury or amalgam indicates improper working. When the indications of color are all right, but the assay shows that no progress is being made, salt must usually be added. Sometimes this condition is only temporary, and is owing to a sudden reduction in the temperature of the air. Generally the defects are owing either to heat or to cold. Excessive heat always signifies a loss in mercury, and should be stopped as quickly as possible by adding cold water or ashes. If the heat is not excessive the *torta* may be allowed to stand a few days. Cold working is remedied by the addition of salt, or of sulphate of copper, or by additional treading. To ascertain which of these is required, careful assays must be made. Generally in the commencement, fresh ore or cement copper is used to correct the working, and toward the close cement copper, ashes, or lime.

When the amalgam is very fluid and easily breaks up into very small globules, and the assay shows that at least 75 per cent. of the silver in the pile is amalgamated, the torta is said to be finished or *rendida*. Sometimes the assay shows everything to be right, but no progress is made for several days in the amalgamation. This is usually owing to a want of

salt, or to cold. If, on examining the black sulphurets, *polvillos*, and rubbing the small metallic globules of mercury or amalgam found among them with the finger, they unite to a large globule, the pile is nearly finished. If they yield a dry amalgam, it is not. The best way to ascertain this, is to make a fire assay of the original pulp and of the torta, and to judge by the yield. When the ores contain galena and blende, these substances decompose the chloride of copper, and the sulphur goes to the copper. The proportion of magistral to be added must, therefore, be largely increased, notwithstanding the fact that the loss in silver is always greater when there is an excess.

When the amalgamation is complete, a considerable quantity of mercury, in addition to that required for the amalgamation of the silver, is added, with the object of making sure the collection of all the mercury and amalgam. In some districts this additional mercury is called *baño*, The pile is still trodden for some time. This last addition of mercury has for its effect to make the amalgam a little more fluid, so that it may be collected more easily, and to collect the floured mercury which would not be caught in the subsequent washing, and to prevent as far as possible further action of the reagents on the amalgam.

There is always a loss of mercury equal in weight to that of the silver contained in the ore. A further loss of from 7 to 10 per cent. comes from that which is mechanically carried off either in the patio or in the washing. With such ores, 40 per cent. of the silver is often lost. The loss of mercury is often from 100 to 200 per cent. of the weight of the silver obtained. As a mean it is from 140 to 160 per cent. or 7 or 8 times the loss in the Freiberg barrel amalgamation process. The attempt was made to diminish this loss by adding a little iron, but in order that the effect may be sensibly felt, a large amount must be used, which increases the expense and does not diminish the loss much. In some of the works the mercury is replaced by an amalgam containing 30 per cent. of copper, which reduces the loss materially. The effect of the copper is the same as that of the balls of copper or iron which are used in the Freiberg barrel amalgamation process. Too much copper, however, must not be added, or it would make the amalgam of silver too friable. The loss in silver is increased by this method, but the loss in mercury is reduced to 120 to 150 per cent. The attempt was also made to use

a lead or tin amalgam, but this was too viscous, and became easily reduced to powder, so that the loss in silver was increased.

At the end of a time, more or less long, no mercury is found. The operation is nevertheless continued until the amalgam attains a certain consistence. If, however, the amalgam becomes too thick, a fresh charge of mercury must be made, adding it little by little. Sometimes the assays are made over only a small part of the torta. A little salt will be added in one part and a little magistral in another. Assays are then made to see the effect, in order to show what should be done with the whole pile.

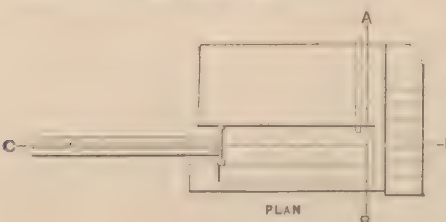
When the *torta* is *rendida*, it must be washed as soon as possible, If allowed to stand, the sulphur and the sulphate of copper which have not been decomposed commence to act, and cause a considerable loss of silver in the state of very finely divided amalgam, *desecho*, which will not unite. It is to prevent this as much as possible, that the large excess of mercury is added, but notwithstanding the excess of mercury the pile must be washed at the earliest possible moment.

c. Separating the Amalgam.—The amalgam, with the excess of mercury, is scattered through a large mass of pulp, from which it must be separated by washing. This should be done once in twenty-four hours.

The washing, *lava*, is done in a box settler, *lavadero*, or in a tub, *tina;* both of these methods being in use in different works. The former is by far the most ancient. The tub, which is very much like the dolly tub or settler of California, has been in operation for many years, but as it requires the use of power, is only adopted in the large haciendas.


Fig. 2

SECTION ON C.D.



LAVADERO (Settler)

Fig. 3.

The box, *lavadero*, Figs. 2, 3, 4, is built of stone on the sides, and lined with cement. It is two meters long, half a meter wide, and one meter deep. It has a

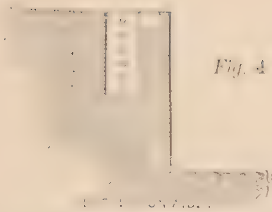


Fig. 4

SECT. OF A PATIO,

platform on one side on which to pile the material to be treated.

The front is closed with plank in which there are six holes, 0.05 m. in diam., five of which are closed with plugs of wood. These serve to let off the slimes. In front of these holes is a vertical wooden trough which carries the slimes to an inclined trough, the bottom of which is provided with several mercury traps to catch any mercury or amalgam that may be carried off.

The *lavadero* is built directly against the patio, the pavement coming up to its front wall. The material from the *torta* is carried to the platform of the settler by a pair of steps built on the platform side. The box is first filled half full with water. Two men then get into it, while one man on the platform shovels the ore into it. The men dance in the water, keeping it in motion with their feet, but keeping their hands out of it. The pulp and water are added little by little, the pulp by a single spadeful at a time, until the slimes flow out of the top hole, while the water is allowed to flow in only as fast as it flows out. The discharge falls down the vertical to the inclined trough, over the mercury traps and riffles, and goes from there to the settling tanks. The heavier liquid below is from time to time discharged by removing the lower plugs. The men are obliged to use a great deal of discretion at this work. If they work too fast, there is danger that some of the amalgam and mercury will be carried off. If they work too slow, the heavier particles collect at the bottom, and the small particles of amalgam sink through it slowly or not at all. They know by experience from the difficulty of moving their feet, when it is time to discharge through the lower holes. They never allow the lower part of the box to become filled. The amalgam is not removed until after the whole of the *torta* has been washed, then the supply of water being kept up, the plugs are removed one by one and the amalgam collected.

In some districts where wood is cheap, the tub is substituted for the stone box. The agitation in this is done with shovels or poles from the sides. No better results are obtained, but the

labor is less severe. These box settlers can only be worked during the day, and must, on account of the danger that some one else may remove a part of the amalgam, be cleaned up every night. They cost but little to build, but require the labor of six men, treading, charging and bringing the pulp. As capital is scarce, but labor very abundant, the use of this settler is almost universal in Mexico.

Sometimes the washing of the *torta* is done in wooden tub settlers, *tinas*, which are usually driven by water power. They are from two to five meters in diameter, and one and a half to three meters deep. The shaft carries four arms, which are fitted with pieces of wood 0.06 m. square and 0.10 m. apart, which reach to within 0.30 m., or less, of the bottom of the tub. In the sides of the tub there are two holes, one 0.8 m. from the bottom, which is 0.15 m. in diameter, from which the tub is emptied; the other, 0.25 m. from the bottom, is 0.02 m. in diameter, and from it the water overflows, and the tail assays are taken. The axis is geared by wooden gearing to a water-wheel. These tubs were formerly constructed of stone. Three of them communicating with each other, were placed together, and were connected by one large wheel driven by two mules trained especially for the purpose. The first of these tanks, into which the pulp was put, was called *tina cargadora*, the third, from which the discharge was made, was called *discargadora*, or discharge tank. In some of the works these tanks are disconnected, though driven by the same power, each tank being used by itself. The tank is filled one-third full of water, and the axis is set in motion quite rapidly; when mules were used they were set at a full gallop, and a charge of 300 kilos. thrown in. Water is added until it reaches nearly to the top of the tub, and the speed reduced until it is just sufficient to keep the pulp off the bottom. In about an hour the assays taken from the top hole show that the mercury has all settled. The bottom plug is then removed, and the contents of the tub discharged into the settling tanks. This is a much better and quicker method of working. There is no danger of the tub becoming clogged at the bottom, and there is no necessity for constantly cleaning up at very short intervals. The tub can be kept going night and day until the whole *torta* is washed, without any danger of

having a clean-up made by others. It will undoubtedly take the place of the box settler wherever there is sufficient capital to erect it.

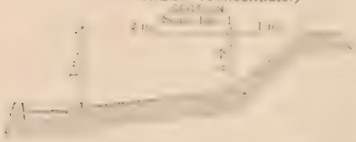
When the whole *torta* has been washed, the *patio* must be carefully scraped, and also the interstices between the stones, to remove any particles of pulp, amalgam or mercury. All these scrapings, *raspadura*, are mixed with the last of the pulp, and are thrown into the settler. The time required to work depends on the number of settlers. It is usually not less than two or three days.

The tails from the *lavadero* or *tinas* consist mostly of iron pyrites mixed with the black sulphides and some ore, their proportion being different with the different ores treated. They are called *cabezilla* or *cabezuela.* They contain some amalgam which is recovered. Formerly* they were carried in wooden *bateas* to a tank filled with water, called the *pila apuradora*, On its surface a wooden bowl, *batea apuradora,* floats, which is from 1 m. to 1.50 m. in diameter. The man who washes with this *batea* leans on the side of the *pila*, and taking hold of the bowl with both hands gives it a peculiar motion, taking up a small quantity of water, which after going round the *batea*, is discharged, taking some of the *cabezilla* with it. The residues are treated on the patio. Generally the tails from the *tinas* and *lavadero* are run over riffled launders, where some of the mercury and amalgam is caught, into two tanks connected with each other, which for a *torta* of twelve to fifteen tons, are five meters long, three wide and one deep. These are called the *tanque* and *contratanque.* The object of the first is to catch all the heavy materials, such as the amalgam and the coarse particles of pulp. Most of the material containing silver and gold is caught here. The *contratanque* catches only the lighter particles, which are much poorer, and are always kept separate, unless found by assay to be of approximately the same value. The tails from the *contratanque* run to waste. The materials caught in both tanks are concentrated in the *chuza*, Fig. 1. Some amalgam, generally not less than 15 kilos., is caught here, the amount varying with the care that has been taken in the washing.

*Phillips' Gold and Silver, p. 344.

Fig. 5.

PLANILLA (Concentrator)

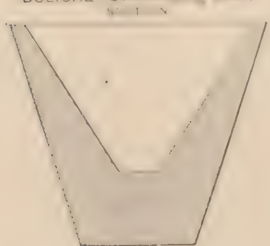


Width of Planilla 2 Metres

The tails from here are concentrated on the *planilla*,* Fig. 5, which is a platform of masonry from one and a half to two meters wide, and with a slope of one meter in ten towards the trough, which supplies a small stream of slowly-running water.† The wall at the upper side is sloped, and furnishes a space to pile up the tails to be washed. The workman, *planillero*, sits on a strip of board put across the water trough, and with a horn spoon containing about a quarter of a liter throws the water upon the pile of tails. The operation is commenced at the lower left hand corner, and continued across the *planilla*, going back again when the *planilla* has been crossed to the lower left hand corner, and working always in the same direction. The water is thrown in such a way as to spread out as much as possible, but not to splash. When this has been repeated several times, the sand for about one meter from the water-trough is thrown away. The heavy particles are thrown up on the pile, and the operation recommenced. When the supply of tails is exhausted others are added. The result of the washing is a small heap of black sulphurets, called *polvillo.*

Fig. 6 .

BOLICHE (Concentrating Bowl)



Scale 20:1

These are further concentrated in a wooden bowl called a *boliche*, Fig. 6, which has the shape of an inverted truncated cone 0.62 m. in diameter, and 0.4 m. deep, which is a hand device in every way similar to the keeve used in dressing copper ores on Lake Superior,‡ and in the concentration of gold ores in California.§ The *boliche* is sometimes made as deep as 0.8 m., and correspondingly large, though this

* Patio Process at St. Dimas. Trans, Am. Inst. Min. Eng., Vol. 11.

† Annales des Mines, 6th series, vol. 20, plate II, Figs. 5 and 6.

‡ Metallurgical Review, Vol. 2, p. 400. § Engineering, Vol. 31, p. 404.

is not usual. Water is put into the *boliche*, and the sulphurets added and stirred, and then allowed to settle. During the settling it is tapped on the outside with a stick or mallet. The heavy particles containing the sulphurets settle to the bottom, and the sand is on the top. The water is soaked off with rags. The sand is scraped off and thrown away. Below is a brownish layer of poor sulphurets called *colas*, which are removed to be roasted. Below them are the clean *polvillo* and a small quantity of amalgam. The *polvillo* is sent to Europe with the high grade ores for treatment. The roasting of the *colas* is done in an ordinary pile with a central chimney. It is put in layers 0.25 m. thick, and is used damp in order to be able to manage it better. The cover is made of earth. The pile is set on fire, and when the roasting is completed the half burned sticks are removed. Only a part of the material is properly roasted, but it is all ground in an arrastra and added to the *torta*. In some places where fuel is cheap, the roasting is done in a reverberatory furnace, and is consequently much better done. There is always great uncertainty in roasting in piles. This roasted material was formerly treated in a *torta* by itself; but it consumes a great deal of mercury, and does not give very satisfactory results. It is much better to mix it in the piles with the ore.

In some places, during the washing, a product is obtained which contains gold and silver, and though there is not much of it, it is richer in gold and silver than the original ores, and also contains some little amalgam. As the material is mostly pyrites, it is concentrated, ground and roasted, and used as a magistral. Sometimes 2 per cent. is obtained in this way.* Of late years, in some *haciendas*, all the tails of the different operations have been treated by the Von Patera process.†

4. Treatment of the Amalgam.

The liquid amalgam is carefully removed from the bottom of the settler. All that caught in the the mercury traps is added to it. This is carried to the mercury house, *azogueria*, and put

* Eng. Mining Inst., Vol. 33, p. 104.

† Trans. Am. Inst. Min. Engs., June Meeting, 1883.

into a large trough, originally always of stone, but now often made of iron. When the whole has been collected, a large amount of mercury, usually ten to fifteen per cent. of the quantity of quicksilver used in the arrastra, is added to the amalgam in order to clean it. It is covered with water to prevent splashing, and carefully worked over. Whatever impurities rise to the surface are removed with a cloth, and fresh water is again added. This operation is repeated until the surface becomes and remains bright. The amalgam is dried and weighed, and is then put into a conical canvas bag, like those used in the West, which is called *manga*, set over a receptacle made of hide, *pila*, to catch the drippings, which, as they contain some little silver, are of more value in the next charge than pure mercury. This is put into flasks for preservation. The amalgam, free from every thing except mercury, *copella*, after hanging several hours, is ready for retorting.

At Chihuahua,* where very rich ores of native silver are treated, the amalgam looks like a coarse sand, but by the addition of mercury the dirt is removed from it. This dirt, however, is very rich, and is further concentrated. When particularly pure silver is required, it is carefully washed, and ground on a stone, in order to remove the sulphide of silver ; the result is a very pure amalgam, which yields silver purer than fine bars. The amalgam cleaned with mercury is strained in canvas cloths, and the quicksilver pressed out into small balls 0.05 m. to 0.06 m. in diameter, by rubbing them with the hands. This is the only way they have been able to get very high grade silver.

Formerly, all the amalgam was beaten and pressed into an iron mould, to make bricks of amalgam, *bollos*, of such a shape that when six were placed together they formed a circular cake with a round hole in the centre. One ton of these was piled on iron supports, over a stone tank filled with water to nearly the top of a copper or iron bell, *capellina*,† which is 0.90 m. high, and 0.45 m. in diameter. This left a space 0.02 m. between the amalgam and the bell which was lowered to its place by pulleys. A wall of *adobes*, leaving a

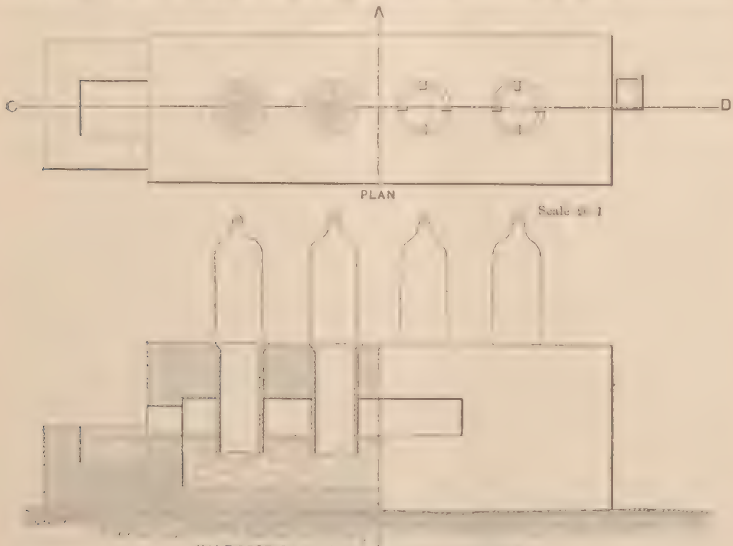
---

* Mining Commissioners' Report, 1872, p. 437.

† Annales des Mines, Vol. 20, Pl. 2, Fig. 2.

space 0.20 m. between the bell and the wall, was then built around it and fired with charcoal for fifteen hours, and removed when cold. The yield of silver was about 200 kilos., and the charcoal used about 250 kilos. per charge. This process is now abandoned.

In the more modern method, the strained amalgam is charged into quicksilver-flasks from which the bottom has been removed. Into these flasks others, open at both ends, are fitted so that the lower parts are beneath the surface of the water, in a tank placed under the furnace. The two flasks are luted so that the quicksilver has no outlet except into the water, where it condenses, as the screw in the upper part of the upper flask has been firmly set. The inside of the flask is then washed with milk of lime or lined with brown paper, to prevent the silver from adhering to the sides. To be sure that the amalgam fills the whole flask, it is first rammed in, and then pounded



QUEMADERO FOR RETORTING SILVER AMALGAM.

Fig. 8.

down with a heavy mallet. 30 to 35 kilos. are charged in each of the flasks, which are then set aside to drain off the excess of quicksilver, and to allow the amalgam to harden. As

soon as 3 to 4 flasks are ready, they are taken to the retorting furnace, *quemadero*, Fig. 8, where they are set on end over holes on the slab which forms the bottom of the furnace. This slab is 0.60 m. above the ground. The size of the furnace is very variable, depending on the amount to be treated. It may have places for 8 to 10 retorts. The amalgam is kept in place by four narrow strips of iron set into the mouth of the flask, and bent so as to cross it beneath the amalgam. The space between the upper and lower flasks is covered with an iron plate full of holes 0.005 m. in diameter, which is luted to both the upper and lower flask. There is no danger of the amalgam falling out, except with an improperly managed fire. This furnace has entirely superseded the old *capellina*.

A wash of clay, about 0.005 m. thick, is put around the upper flasks to protect them from the air. A brick wall laid up temporarily is then built round all the flasks, and a charcoal fire is made inside of it. The first object of the fire is to dry the clay coating; it is therefore made to burn very slowly at first, so as to make it dry without cracking. When this has been done a brisk fire is made over the whole of the flasks. Water is kept constantly flowing into the tank below the flasks, both to keep up the supply and to keep it cool. The mercury driven out of the amalgam falls into the water and collects there.

The operation needs care. If the temperature is raised too high, there is danger of melting the amalgam. If raised too quickly, there is danger of explosion from the rapid formation of the vapors of quicksilver. If the heat is not high enough, the bullion is impure from excess of mercury. As a precaution against this, the purchaser has a right to heat the bars of silver red hot to drive off any excess of mercury, but if the bars melt while undergoing the process, the purchaser pays for them at their weight before heating. If they do not, the weight after heating is accepted. When the work is properly done, the silver still contains one per cent. of mercury. The mercury collected in the tank is not entirely free from silver, and must be strained. The amalgam collected is called *estrujon*, is much drier than the other amalgam, and is retorted by itself when enough has been collected to make it worth while to do so.

The retort silver, *plata pasta*, is refined in a small reverbera-

tory furnace built of *adobes*, and heated with wood, which receives a charge of 300 kilos. of the crude bullion. This charge is refined in four hours. A little litharge and lead are added to remove the impurities, which are generally sulphur, arsenic, lead, iron, and sometimes zinc. Borax and carbonate of soda are used as a flux. The loss is seven per cent. of the crude bullion, and consists mostly of quicksilver, but to some extent of silver.

The silver obtained is quite pure: it contains at San Dimas .994 of silver, .0033 of gold, leaving only .0026 for base metals. At Chihuahua it is .998 from the arrastra, and .990 from the treatment of the tails.* The bars weigh 35 kilos. The slags from the refining furnace, with the tails from the tanks for washing amalgam, and other products, are occasionally smelted in a shaft furnace with the addition of galena, and the lead is used in refining retort silver.

The loss of mercury in retorting varies from two to six kilograms per ton. The total loss of mercury in Mexico has been for many years calculated on the supposition that it requires a loss of a unit of mercury for every unit of silver obtained. This being a fixed amount, is called *consumido.* Any amount above this which is not recovered is called *perdida*, or loss, and is always attributed either to carelessness on the part of the workmen, or to mechanical losses during the operation. The losses, both the fixed and the variable, are always referred to the Mexican *mark*, which is equal to 248.83 grams.

Consumido,	248.83 grams.
Perdida,	124.42 "
Total loss,	373.25

The loss of mercury for sulphuretted ores of from $60 to $100 will be, under the most careful management, not less than four to five kilograms. In some exceptional cases it has been three kilograms for every kilogram of silver extracted. The richer the ore the greater the loss. It may be averaged at one and a half kilograms for every kilogram of silver produced. With ores containing large amounts of native silver, the loss is proportionately much less, and sometimes even less in amount. The loss in

* Mining Commissioners' Report for 1872, p. 438, Washington, D. C., 1873.

silver varies from 20 to 25 per cent. of the assay value of the ore. Some amalgamators claim that they can save as much as 80 or even 85 per cent., but this is doubtful, even with the ores most easily treated. When the ores contain much blende and galena the loss easily reaches 25 to 30 per cent., and if in addition to this there is any amount of antimonial or arsenical sulphides, it will reach as high as 40 per cent. A part of this loss is, of course, counted with the loss of the amalgam, which is carried off in fine particles. It could easily be reduced by better appliances for catching the mercury, and better washing and concentration, to catch a larger part of the pulp not acted on. But there is a mechanical loss as well as a chemical one, which must in any case be large. Just as soon as it is possible to introduce all the modern methods of concentration, the conditions will be such that other processes will take its place. Although much has been done to improve it, no process with large losses in the precious metal and excess of labor, can hope to stand before increased facilities for transportation. When gold is contained in the ore as a sulphide, not more than 40 per cent. is recovered; when it is free, 75 per cent. is often saved.* The cost of the process will of necessity vary in different localities under dissimilar circumstances, and with ores whose composition is not the same. The results vary from year to year. Phillips gives the mean cost per ton for reducing these ores as follows:†

COST OF TREATING ORES.

Coarse crushing in dry stamps and subsequent fine grinding in arrastra,	$1.90	
Manipulation in patio,	4.50	
General expenses of management,	1.20	
Repairs,	1.20	
		$8.80
Sulphate of copper,	$3.20	
Salt (1.6 quintals per ton),	6.50	
Quicksilver (11 oz. per 8 oz. of silver),	6.50	
		$17.00
		$25.00

* Eng. and Min. Jour., Vol. 33, p. 104.

† Phillips's Gold and Silver, 1867, p. 357.

Mr. Rul* gives the cost in detail as follows, for a much more recent period.

COST OF GRINDING ONE TON OF ORE.

Mules,	$0.115
4 workmen,	0.148
1 mule-driver,	0.055
Repairs,	0.044
Night shifts,	0.208
	$0.570

COST PER TON OF WORKING TEN QUINTALS EACH IN THIRTY ARRASTRAS.

Mules,	$1.871
1 foreman,	0.142
1 helper,	0.077
3 feeders,	0.099
5 arrastra men,	0.219
3 watchmen,	0.132
3 men,	0.099
Bottom-stones,	0.116
Grinding-stones,	0.357
	$3.112

PATIO WORKING, PER *Repaso.*

Mules,	$0.029	
7 workmen,	0.021	
	$0.050	
14 repasos at 5 cents,		.70
Salt,		1.55
Sulphate of copper,		0.96
Labor,		0.17
		$3.38

SETTLERS AND DISTILLING.

Mules,	$0.082
Various expenses,	0.417
Charcoal,	0.066
	$0.565

* Eng. and Min. Jour., Vol. 33, p. 105.

GENERAL EXPENSES.

Salaries,	0.713
Rent,	0.274
Repairs and miscellaneous,	0.384
	$1.371

TOTAL COST OF WORKING PER TON.

Cost of grinding one ton of ore,	$0.570
Cost per ton of working 10 quintals in 30 arrastras,	3.112
" " " Patio working,	3.380
" " " settlers and distilling,	0.565
" " " salaries, rent, repairs, &c.,	1.371
	$8.998

This estimate takes no account of the mercury lost, estimating this at about $7.00. This would make a cost of $16.00, a much lower figure than that given by other authorities. Mr. Chism gives as the cost of working a $60 ore in ten ton tortas as follows:*

COST PER TON OF 2,000 LBS.

Breaking per ton,†	$1.53
Grinding,	1.40
Scraping arrastra to get out the gold amalgam,	.13
Carriage of slimes from arrastra to patio,	.60
Mules hired,	1.73
Labor, including driving and tending mules, spading and washing *torta*,	1.80
Salt at 6 Mexican dollars per *carga* of 98.3 litres,	2.80
Sulphate of copper at $0.25 (Mex.) per pound,	1.33
Charcoal for retorting and assaying at $0.37½ (Mex.) per *arroba*,	.33
Quicksilver at $0.62½ (Mex.) per lb.,	4.68
Salaries, general expenses, including keeping and feeding of mules,	6.66
Repairs,	2.33
Concentration of sulphurets,	2.26
Total,	$27.58

The expense of working with *tortas* of this size is much greater than if the pile were more than twice as large. When the *tortas* were of 19 tons and all the machines were driven by water power, the expense was as follows:

* Trans. Am. Inst. Min. Eng., Vol. 11.

† Breaking a ton of large ore costs $2.66, but as the smalls are also worked the average cost is as stated.

COST PER TON OF 2,000 LBS. IN WORKING A *torta* OF 19 TONS.

Breaking, grinding, and use of tools,	$6.66
Amalgamators' wages,	1.66
Scraping arrastra to get out gold amalgam,	.16
Carrying and washing scrapings,	.11
Concentrating tailings of "	.07
Carrying slimes from arrastra to patio,	.42
Mules and keeping,	3.72
Labor, spading and mule-driving,	1.60
" washing *torta*,	.56
Charcoal for retorting silver,	.47
Concentrating tailings of *torta*,	2.06
Materials, salt, 600 lbs at 8 cts.,	2.53
" sulphate of copper, 125 lbs at 25 cents,	1.65
" precipitated " 25 " 66 "	.87
" quicksilver, 133 " 62½ "	4.37
Total,	$26.91

There is not only a very great saving in doing the work by power, but in custom mills, to which these last expenses refer, there is a considerable profit included in the cost, which will not be less than from two to two and a half dollars per ton. It is astonishing how such a process has been able to retain its hold nearly three hundred years. In every country where it has been introduced, it, like many another historical process, has yielded before the advance of rapid means of communication, as this undoubtedly will in Mexico. It costs but little to carry it out, and it can be worked on a large scale as well as a small one, the latter having only this disadvantage, that it increases the loss. The process requires peculiar conditions of climate, which adapt it especially to hot countries. On account of the climatic conditions it has been abandoned in the West, where it was formerly used. It always works better on a hot day than on a cold one, in summer than in winter. The cheapness of the plant more than compensates for the time, as money in most of these countries is scarce, while time is of no value. Working the tails by the Von Patera process has, in some places, added to the yield in silver and increased the profits. The loss in reagents is easily put up with, as it is the only means by which the precious metals can be obtained. The method is only applicable to such ores as contain the silver native, or as chloride, bromide or iodide,

associated as they usually are with highly oxidized substances. The presence of much sulphide renders the losses large. The process becomes difficult with the arsenio and antimonio sulphides, and impossible when there is much galena, blende, tetrahedrite, or bournonite in the ores. Not the least of the disadvantages of the process is the facility with which other people than the owners may make a clean-up, the only protection against this being the difficulty of selling unrefined silver, especially in small quantities. In very large works where much capital is invested, the item of time is a matter of consequence, but there seems to be no other process possible until transportation shall become less difficult.

THE CAZO PROCESS.

There seems to be no doubt that the *patio* process was in use in South America up to about the commencement of this century. It was still used there, to a very limited extent, until the year 1830, at which time it seems to have been quite generally given up, probably on account of the very large quantity of *negros* or sulphurous ores which began to be found. It was replaced in part by the Cazo, or caldron method, which is still in use there, and in some parts of Mexico, and partly by a new method in which the copper bottom was replaced by an iron one, and finally by still another process, which, while it imitated the pan amalgamation method so far as the machinery was concerned, added the chemicals which were supposed to form in the *Patio* already prepared. We shall briefly describe all these processes.

The *Cazo* process was invented in Chili, in the year 1609,* by a priest, Albaro Alonzo Barba, who, in his description of his own process, insists that the vessel in which the work is done should be made entirely of copper, though this was long since found not to be necessary. The ores to which this method is applied are the rich surface ores—chlorides, bromides and iodides, which, if they are not rich enough, must be concentrated on the *planilla*. The process yielded nearly the whole of the silver which is in them. The loss in mercury is from twice to two and a half times the total quantity of silver contained. The operation

* Percy's Metallurgy of Gold and Silver, Part I, p. 656.

lasted not much over two hours, and gave tails which did not contain more than \$3 to \$4 to the ton, but it was only applicable to ores which contain \$80 and upward per ton, free from sulphur.

This process was formerly used in connection with the *patio*. The ores were first stamped and ground in the arrastra. This is done as a preliminary to a concentration. The grinding is not done so fine that there is danger of any large part of the silver being carried off in the washings. From the arrastra the pulp is carried to the *planilla,* where it is concentrated to such an extent that the concentrates do not represent more than two or three per cent. of the original ore. These concentrates are treated in the *cazo*, while the tails, if rich enough, were formerly treated on the *patio*. There are two processes known under the name of the *cazo*, distinguished from each other by the size of the vessel and the mechanical means of doing the work. The *cazo* is the smallest vessel. The larger one, constructed on exactly the same principle, is called a *fondon*. The process itself is very simple and rapid. It consists in boiling the concentrates, keeping them constantly agitated with salt and sulphate of copper, to which mercury is added, and then treating the amalgam.

The *cazo*, as originally invented, was a round vessel made entirely of copper, but was afterwards replaced by a vessel, at first made of stone, and then of wood, with a copper bottom turned up at the sides. This vessel was originally quite small. Its dimensions were: diameter above, 1 m; diameter below, 0.60 m.; depth 0.45 m. The thickness of the copper bottom was 0.05 m to 0.06 m. This was set over a fireplace without grate, bars or chimney, the smoke going out where the fuel was put in. A *cazo* of such very small dimensions could treat only about 50 kilos. at a time.

To treat the ore, water sufficient to make a thin pulp with the charge, was introduced. The fire was lighted, the water brought to a boil, and salt amounting to from 5 to 15 per cent. of the weight of the ore was then added. The workman then rubbed the bottom of the *cazo* with a piece of wood attached to a long pole, to keep the copper surface perfectly free. If the salt had been added before the ebullition of the pulp, it would have collected on the bottom, from which it would have been difficult to separate it. As soon as all the salt is dissolved, the first

addition of mercury is made. This will generally be introduced in several portions; one quarter only being added at first. In ten or fifteen minutes an assay is taken, with an open horn attached to a long handle, so as to pick out the heavy parts of the ore and amalgam. This is washed, and if the amalgam shows itself as a clear gray sand, *polvo*, the charge is ready for the second addition of mercury. The same quantity as before is added, the heat and movement being kept up. In an hour or two after the start, another assay is taken, and another addition of mercury made, and so on until an amalgam containing two parts of mercury for one of silver results. The operation is then considered as finished. The amalgamator, *cazeador*, takes a last assay, *prueva en crudo*, which he washes to get out the gangues, then adds a large excess of mercury to dissolve out the amalgam, separates it from the tails, and then examines it by rubbing it against the sides of the vessel to see if any of the ores remain. If they do, the operation must continue; if not, and the amalgam remains fluid, it is stopped. At the end of six hours the operation is complete. The muddy material is run off into outside receptacles, and what remains in the *cazo* is dipped out, and treated in *bateas* with an amount of mercury equal to that which has already been used.

It is of the greatest importance, during the whole of the operation, to prevent anything from adhering to the bottom. If the salt was introduced before ebullition took place, it would collect on the bottom, and the apparatus would have to be emptied before it could be removed. It is more especially important to prevent any adherence of mercury, which would prevent the action of the salts of silver on the copper, and thus make the amalgamation progress very slowly. It would besides cause a great loss in mercury, as it alone, and not the copper, would reduce the silver salts. If the proportion of the mercury and silver are as two to one, no adherence of the mercury takes place.

The *cazo* was replaced by a much larger vessel,* 2.15 m. diameter above, and 1.80 m. below, and 0.85 m. deep, called a *fondon*.

* Ann. des Mines, 6 s., Vol. 20, p. 216, Pl. III, Fig. 7.

The bottom is made of impure cast copper, and is 0.18 m. to 0.20 m. thick, 1.80 m. in diameter, and 0.18 m. deep. On the inside of the rim of the basin a place is cut out to receive the staves, which rest on the bottom of the cut made in the rim of the copper basin. These staves are 0.70 m. long, and are held in position by iron hoops. All the joints between the copper and wood are made tight with clay, and then adobes are built up around the whole to a thickness of 0.45 m. In the centre a raised space is provided for the pivot of the upright arbor which carries two arms, one 0.45 m. from the bottom, of a little less diameter than the interior of the *fondon*, and the other at 0.85 m., projecting beyond it for the purpose of hitching a single mule to it. The lower arm carries two pieces of copper, each of which weighs 140 kilos., which are used as mullers. They must be so arranged as to rub over the whole surface of the copper bottom to keep anything from becoming attached to it, as it would otherwise be impossible to grind with such soft materials as a copper muller. The whole is placed over a furnace with grate bars, on which the inferior fuel of the country is used. Such a *fondon* will last for ten years. The cost is*

60 quintals of copper for bottom, at $20, - -	$1,200
Two mullers, - - - - - -	120
25 staves at 3 reals, - - - - -	9
Furnace, - - - - - -	40
Wood-work for the mules, - - - -	10
House, - - - - - -	200
	$1,579

When everything is ready, the *fondon* is charged with 500 to 600 kilos. of rich ore, and 30 to 40 kilos. of the powder of unwashed ore, and sufficient water to form a thin mud. Fire is kindled on the grate, and the muller set in motion. At the end of two hours the material is boiling; 52 kilos. of salt, or about ten per. cent. of the weight of the ore, are added. This relatively large amount is necessary, as the success of the process depends to a great degree upon the quantity of salt used, and the velocity of the mullers. With the richest ores, the quantity of salt does not ex-

* *Ibid.*, p. 217.

ceed 25 per cent., and whatever may be the necessity for it, the number of turns of the muller will hardly exceed ten. About half the weight of silver contained in the ore is then added in mercury, and the mullers set in motion at the rate of ten turns per minute. The amalgamation commences at once. At the end of an hour an assay is taken from the bottom, taking care to take it ahead of the muller. If the amalgam washed out looks like light grey sand, it is composed of two of mercury for one of silver; the same quantity of mercury is again added, and at the end of an hour another assay is made, and so on, until the amalgam, even after it has been worked in the *fondon* for half an hour, shows an excess of mercury. The *prueva en crudo* is then made, and if any ore is found, the operation is continued half an hour without any addition of mercury. At the end of six hours the operation will generally be finished.

If there is an excess of mercury, there is danger that the sides of the vessel will be attacked; if there is no excess, but if the velocity of the muller is decreased, the copper and mercury become alloyed, and the bottom of the *fondon* becomes coated with a very thin coating of silver amalgam which is very difficult to remove. As the copper surface is much diminished, the operation is very considerably lengthened. There is also danger that the mercury will flour, and the loss in silver will be very great. There is only one remedy for this, which is to empty the *fondon*, and scrape the bottom clean. It is very easy to prevent this accident by adding the mercury carefully and in small quantities at a time, and by keeping up a uniform but rapid motion of the mullers. With these precautions, the work is very nearly independent of the skill and intelligence of the men. The results are quite uniform, and are obtained in a very short time.

As the reactions are not performed at the expense of the mercury, there is no occasion for any loss of it. If the operation is well carried out, all the mercury used should be collected at the end of the process; but this is never done. Some of it is floured, some of it volatilized, so that the loss is counted at about two per cent. The reason why there is such a small loss probably is that the work is done hot. The loss in silver is variable. The ores almost always contain sul-

phides more or less rich in silver, which are not acted on by this method. The tails vary from twenty-five to forty dollars to the ton, so that the *fondon* process can generally be used only as a preliminary method, and the patio, or some other process, is usually associated with it. The residues remaining in the fondon consist for the most part of the oxides of lead and iron, and some sulphurets containing silver and floured mercury. These are washed in large wooden bowls in a water-tight vat, adding as much mercury by weight as there is material to be treated, in order to collect the flour. The amalgam is treated as usual.

In Mexico, the slimes which have been removed are put into catch-pits where the excess of water evaporates. They are then made into small *tortas*, which are trodden by men. Two to two and a half per cent. of salt is added to them, but no magistral, for the water coming out of the *fondon* contains enough copper salts to do the whole of the work. The amalgamation is conducted as usual, except that it is very slow, lasting often as long as three months. The loss in silver is as much as 20 to 25 per cent. The mercury used is 125 to 150 per cent. of the silver contained. This method is one of the most rapid and least expensive of the Mexican processes. The cost is given below:*

Cazeador (amalgamator), - - - -	$0.500
Atizador (furnace man), - - - -	0.280
Wood for heating the furnace, - - -	1.562
Salt, 75 lbs., at $6 for 300 lbs., - - -	1.500
Mules, - . - - - - -	0.187
Mercury, two per cent., loss, - - -	0.416
Cost of distillation, etc., - - - -	0.250
	$4.665

In a single operation 1,200 pounds of ore are treated, which is 9.33 reals per charge.

If to these the expenses of dressing and concentration on the *planilla* are added, calculating the expenses in grammes of fine silver per ton, we have as follows:

* *Ibid.*, p. 221.

			Grammes.
Crushing with mule power,			17.360
" in arrastra,			57.860
Washing on the *planilla*,			17.360
Amalgamation.	Labor	34.720	
	Power	8.657	
	Fuel	72.313	
	Salt	69.443	
	Mercury	19.258	
	Distillation	11.573	
			215.964
Cost in grammes per ton			308.544

The very friable nature of the gangues has much to do with the small cost of the concentration. The cost elsewhere in grammes is:

	Grammes
Cost of extraction and sorting,	92.59
Transportation,	69.44
Treatment,	231.47
	393.50

This includes the cost of mercury, and shows a minimum for the metallurgical treatment. The treatment of these ores gives 400 grammes in the *cazo*, which pays the cost, the profit being in the treatment of the tails.

An attempt was made in Chili* to treat rich sulphurous ores with sulphate of copper and salt, but though it was a rapid process, and the tails were poor, the enormous losses in mercury caused it to be entirely abandoned. It was replaced by a method no longer used, but which is interesting as showing how another grew out of it.

The ores upon which the process is used are the rich bromides, chlorides and iodides of the upper part of the veins. The gangue is oxide of iron, the carbonates of baryta and lime, and some clay. They contain generally from $300 to $400 of silver to the ton. When such ores as these became rare, some other process had to be used. This method caused the almost complete abandonment of the Cazo process proper; and it was not until the ores became so very poor that it was no longer applicable, that it

* Revue Universelle des Mines, Series 1, Vol. 31, p. 489.

was replaced by the process now used in the vicinity of Copiapo.

The ores were reduced to pulp by methods analogous to that in the *patio* process, from which this one originated. The pulp is carried away by a stream of water to settling-tanks 2 m. in diameter and 3 m. deep, made of sheet iron, the number in use depending on the size of the works. As fast as one of these settling-tanks is full, the stream is turned into another, and so on. The tanks, when full, are left from eight to twelve hours. The clear water above is then run off, and the mud below carried to the *tinas*. These are wooden tanks with cast-iron bottoms. They are 1.80 m. in diameter, and 1.20 m. deep. In the centre is an axis which carries a muller, which runs on or close to the bottom of the *tina*. This machine was undoubtedly suggested by the arrastra. The charge for each *tina* is one and a half tons of pulp. It is introduced into the *tina* while the muller is still. Mercury is added, to about twenty times the amount of silver contained in the ore, and the muller put into very slow motion, not over four times a minute. At the end of twenty hours the amalgamation was supposed to be completed. A stream of water was then introduced, and the light particles were thus carried off. When the water ran clear, the particles being too heavy to remain suspended in it, the mercury and amalgam were removed through a hole made in the *tina* for that purpose, and collected in a cast-iron vessel called a *cocha*. A complete operation, including the grinding, lasts about 60 hours. The cost for ores yielding $80 to the ton is $10 per ton, including the loss in mercury. The tails usually contain from $8 to $10 a ton. They are not allowed to contain more than from $25 to $30. As the ores themselves are very pure, the silver obtained is about .990 fine. So long as the ores were rich and pure, little was done to improve the process, but as they became poorer and more impure, the tails grew constantly richer, and it became necessary not only to treat them, but to treat the poor ores, *desmontes*, which had been thrown aside as not worth treatment. Barrel amalgamation was tried, but failed, as did also the attempt to chlorinize the ores and dissolve out the chloride of silver, as the ammonia cost too much. Recourse was then had to the abandoned *Cazo* process, which, with a number of modifications, proved successful.

The process which took the place of this* is a very simple one, applicable to all the ores of silver except argentiferous sulphides of copper, galena, or blende, and to ores which contain more than one per cent. of free arsenic, which causes great losses in the mercury. The inventor of it is not known, but it has been in constant use about Copiapo since 1862.

The ores must be carefully sorted, so as to separate them into different classes, keeping the especially rich ores by themselves, as these are worked much more rapidly than those of lower grade. The difference of time in the treatment of the different ores more than makes up for the trouble it costs.

The rich ores, including the sulphides, are treated in copper tanks with sulphate of copper, salt and mercury. The solutions are all made by steam, and beforehand, five per cent. of the weight of the mineral being added in salt. The sulphate of copper solution is made up to 20° B., and to it salt is added until no more will dissolve. The sulphate of copper is in this way transformed into chloride of copper, and the soda to sulphate of soda. When the liquor is saturated, it is decanted into large wooden tanks, and metallic copper, usually old copper sheathing, is put into the liquor, which is heated to ebullition by a current of steam at a pressure of three atmospheres. This causes the copper to be attacked, and a sub-chloride of copper is formed which is used in the process. The operation is finished when, by taking about 50 c. c. of the liquor and putting it into a liter of water, the oxychloride precipitates as a white powder, leaving the liquor colorless. The sub-chloride is then formed. The salt requires one vat, the sulphate of copper two, and the sub-chloride one, in their preparation. When the sub-chloride is formed it must be used as soon as possible, to prevent the formation of the oxychloride, and in order to do this as far as can be done, the solution is slightly acidulated with sulphuric acid.

A cast-iron Chilian mill, *trapiche*, each wheel of which weighs four tons, is used for grinding the ores. The bottom of the mill is called *solera*. This is usually made of cast-iron, but sometimes of steel. The mill turns at the rate of 10 to 12 turns a minute. The ore, which is ground sufficiently fine, is carried off by a current of

* Revue Universelle des Mines, 1 Series, Vol. 31, p. 493.

water, the quantity of which is regulated according to the fineness to which the ore is to be ground. This water is made to pass through slime-pits five meters by two meters, and one meter deep, enough to run off perfectly clear from the last one. When one of the tanks is full, the stream is turned on to another. The full one is left for 8 to 10 hours. The clear water is then drawn off, and the pulp thrown out with shovels upon an area called *cancha,* to dry. When the ore is sufficiently dry, it is charged into barrels similar to the Freiberg amalgamation barrels. They are of different sizes, their capacity being from one to four tons, the larger the better. Those which hold four tons are 1.80 m. by 1.50, with a thickness of stave of 0.075 m. To the four tons of ore, enough of the salt solution is added to form a thick mud. The quantity of magistral to be added depends on the kind of gangue, much more being required for carbonate of lime than for clay or oxide of iron, as the former decomposes the sub-chloride. For an ore of about $80 to the ton, and a variable gangue, 28 to 30 litres of the magistral are added. The barrels are turned from twenty minutes to half an hour to make the mud quite uniform. Mercury amounting to from 20 to 25 times the quantity of silver contained, is then added. If there is a large amount of chloride or bromide of silver in the ore, twenty-five per cent of the weight of the silver contents of the ore is added in lead. This is amalgamated with mercury before it is introduced, and has for its object to prevent the formation of chloride and bromide of mercury, and a consequent loss. Lead is very easily attacked by the chlorine and bromine set free—much more easily than mercury. This saves the the mercury from being lost as chloride, and also prevents a mechanical loss, as the chloride of mercury, once formed, envelops the globules of mercury and prevents both their coming together in a mass and their action on the silver. Besides this, the mercury is much more easily reduced to a powder by this means, and is kept so, causing a great loss. This simple device of using lead reduced the loss in mercury, when the chloride and bromide ores were used, from 150 per cent. to 25 per cent. As soon as the mercury is introduced, the barrels are turned at the rate of four to five turns a minute for six hours. The operation is then complete. Water is added in considerable quantities, the barrel

being turned for a short time, and the tails, amalgam and mercury discharged as in the Freiberg process. The amalgam recovered is not pure. It contains oxide of copper, produced by the action of the lime of the gangue on the chloride of copper, and the sulphides of copper produced by the action of the sulphate of copper on the sulphide of silver. These must be separated, the one by mechanical means, the other by chemical action. The first is done in a *tina*. The amalgam is charged with ten per cent. of fresh mercury. Water is added, and the muller is made to revolve at the rate of sixteen turns a minute. When the water which comes off is entirely clear, all the sulphide and a part of the oxide of copper will have been removed. To remove the oxide, all the water of the *tina* is run off, and two per cent. of carbonate of ammonia is added. The muller is revolved for five hours. . At the end of that time it is stopped, and the amalgam washed with water. If this has been properly done no oxide will be left. The amalgam is distilled in a *capellina*. The mercury which is strained from the amalgam becomes little by little quite impure. After it has been used five or six times, it amalgamates very slowly. It is then purified by adding to it 20 grams of sodium amalgam for every 100 kilos. of impure mercury.

The resulting silver, *pina*, is refined in a reverberatory furnace. It contains some arsenic, which is extracted by the iron of the tools, and floats on the surface of the bath and is removed. The method of refining does not differ in other respects from that used elsewhere. The silver obtained is 980 fine. By this process, tails which do not contain more than \$6 to \$8 to the ton, and ores of from \$10 upward, are worked. When the ores do not contain more than \$80 to the ton, the tails do not contain much more than two to three dollars. Plenty of good water is a necessity for such works, both for purposes of washing and for power if possible.

To treat eight tons of ore in twenty-four hours, requires an area of 500 square meters for the ores, and one of 1,000 square meters for drying the pulp; two Chilian mills requiring about six horse-power: two settling tanks, and two amalgamation barrels requiring about eight horse power: a vat to collect the water from washing the barrels, to recover the floured mercury; one trough for washing the amalgam: one distilling

furnace; one reverberatory furnace for refining the silver; a tank for the preparation of the magistral, with a three-horse power boiler attached; two vats for dissolving the sulphate of copper; a vat with hydraulic cement to make the salt solution, with a boiler for boiling it; a syphon for clarifying the liquors, which must all be treated with lime to precipitate the copper contained in them;—these constitute the machinery and apparatus for the works. The cost of treating a ton of ore of about $40, not including interest nor sinking fund, would be—

Crushing, - - - - - -	$1.60
Mercury, magistral and salt, - - - -	4.00
Purifying the amalgam, - - - -	.04
Distillation, - - - - - -	.04
Fusion and firing, - - - - -	.09
Various expenses. - - - -	1.00 to 1.10
	$6.87

The whole operation is very simple,—quicker, and with less loss, than the barrel, more certain in its reactions than the *patio*, and applicable to almost all the ores found in Chili. It is even cheaper, under some circumstances, than the lead fusion.

Glossary of Terms Used in this Article.

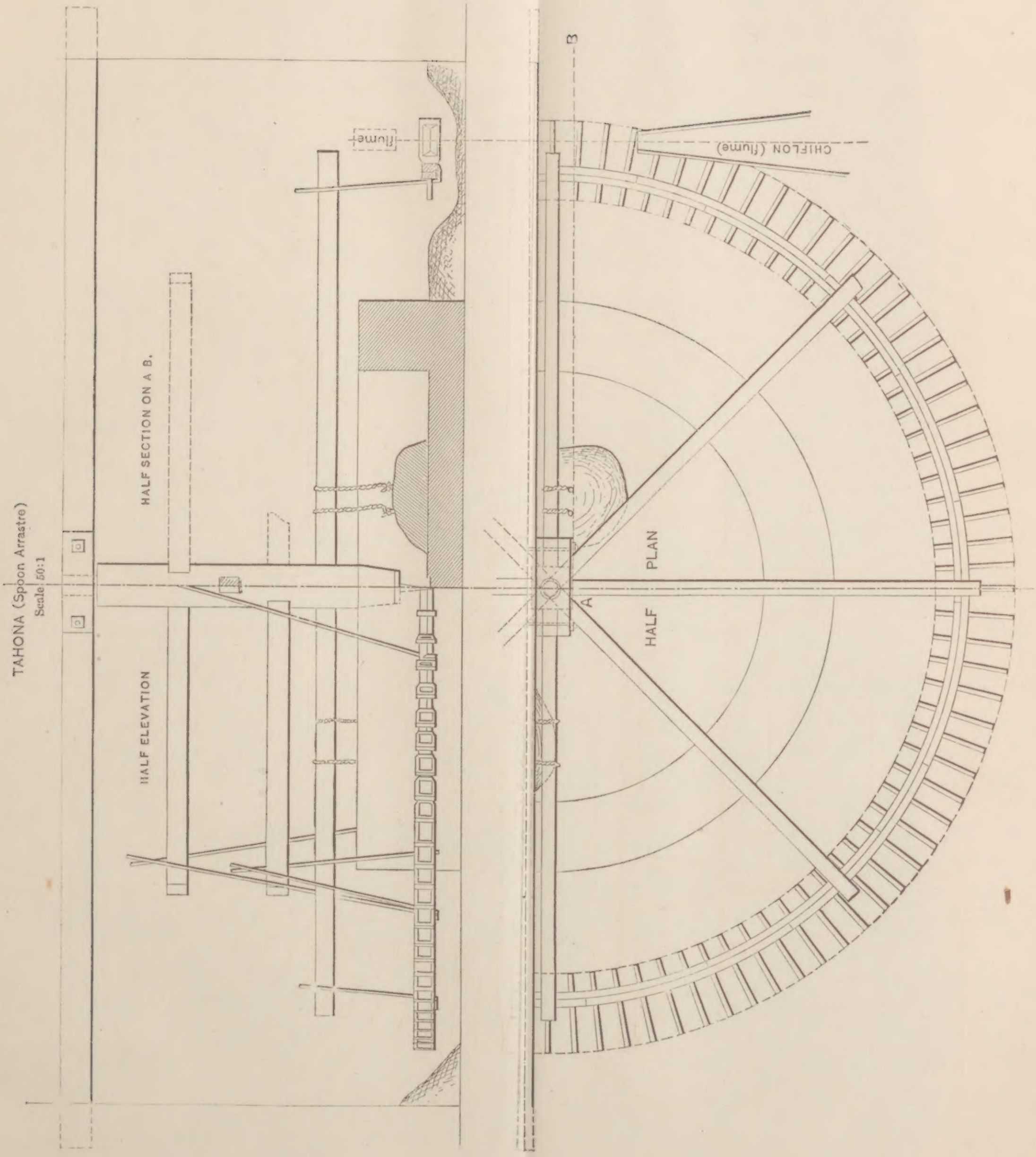
Adobes,	Sun-dried bricks.
Arrastra,	Mexican mill for grinding ore.
Arrastra de cuchara,	A spoon *arrastra.*
Arrastra de marca,	A large *arrastra.*
Arrastra de mula,	An *arrastra* worked by mules.
Arroba,	Mexican weight of 40 lbs.
Atizador,	Furnace-man.
Azogue,	Quicksilver.
Azogueria,	The mercury-house.
Azoguero,	The amalgamator.
Baño,	Excess of mercury used in the *torta.*
Batea,	A bowl.
Batea apuradora,	Wooden bowl floating on the *Pila apuradora* to receive the *cabezilla.*
Bolichar,	Treatment in *boliche.*
Boliche,	Bowl for concentrating.
Bollos,	Triangular bricks of amalgam.
Bonanza,	Rich pocket in a vein.
Cabezilla,	Residue after washing the *torta.*
Cabezuela,	Concentrates rich in gold and silver.
Cajetes,	Walled receivers for the ground slimes. (See *lameros.*)
Caliche,	Feldspar.
Calichoso,	Feldspathic.
Calor de frio,	Steam caused by the difference between the heat of the pile and of the air.
Cancha,	Space for drying slimes.
Capellina,	Bell covering *bollos* while distilling off the the mercury.
Carga,	Mexican weight of 300 lbs.
Cazeador,	Amalgamator.
Cazo,	A vessel with a copper bottom, for heating and amalgamating the ore.
Ceja,	Silvery-white amalgam.

Chuza,	Washer or settler.
Colas,	Brown sulphurets above the *polvillo* in the *boliche.*
Cocha,	A cast-iron vessel.
Colorados,	Colored ores containing silver.
Comalillos,	Calculation furnaces for making magistral.
Consumido,	Fixed loss of mercury.
Contratanque,	Second settling-tank.
Copela,	Dry amalgam in bag after draining.
Copelilla,	Zinc blende.
Cuchara,	A hollowed spoon-shaped float on the arrastra.
Debil,	Term applied to amalgam when very fluid.
Descargadora,	Discharging tank, from which the slimes are run off last.
Desecho,	Broken-up mercury. The attacking of the amalgam by the sulphur, etc., causing loss of silver.
Despoblado,	Ore with much gangue,
Desmontes,	Poor ores.
Ensalmorar,	The addition of salt.
Estrujon,	Amalgam strained from the mercury collected in the basin of the furnace.
Estufa,	Stove for evaporating the mercury from the amalgam.
Ferro blanco,	Arsenopyrite.
Fondon,	A large *cazo.*
Fuerte,	Strong; applied to amalgam needing more mercury.
Galeme,	Lead cupellation furnace for silver.
Galera,	A long shed on each side of the *patio.*
Granza,	Coarse sand from stamping-mill.
Granza de llunque,	Third class ore.
Guija,	Quartz.
Guijoso,	Quartzose.
Hacienda,	Establishment for treating ores.
Ijadas,	Assays of two to five pounds.
Incorporo,	Mixing the magistral and mercury in the *torta.*

Insalmoro,	Salting the *torta.*
Jicara,	A small vessel or bowl in which the assay sample is washed and the amalgam tested.
Jales,	Tailings.
Lagune,	A small lake.
Lama,	Slimes.
Lameros,	Slime pits; walled receivers for the ground slimes. (See *cajetes.*)
Lava,	Washing the *torta.*
Lavadero,	The ordinary settler; washing apparatus.
Limadura de plata,	Dry silver amalgam.
Lista,	Tail of impure mercury.
Magistral,	Roasted copper pyrites, sulphate of copper, etc., used to reduce silver ores in the torta.
Manga,	Canvas bag to drain amalgam.
Marc,	Mexican weight for weighing silver and gold, eight ounces.
Marmajas,	Concentrated sulphides.
Metal calichoso,	Feldspathic ore.
Metal de beneficio,	Second class ore worked on the *patio.*
Metal de exportacion,	First class ore ready for sale.
Metal hecho,	Hand-picked rich ore.
Metal de primera clase,	First class ore ready for sale.
Metal gabarro,	First and second class ore, from the size of an egg to that of an orange.
Metal granza,	Fine ore, smalls.
Metal de labores,	Smalls from the workings of the mine.
Metal de llunque,	Smalls from the cleaners.
Monton,	Mexican weight varying from .75 to 1.62 tons.
Molino,	Stamp-mill for ore.
Morteros,	Stamping-mills.
Negros,	Black ores of silver.
Oroche,	Bullion after retorting.
Pasilla,	Dry silver amalgam.
Patio,	Amalgamation court.

Perdida,	Loss of quicksilver beside the *consumido.*
Pila,	A trough of hide.
Pila apuradora,	Tank to receive the residues from the washing-tanks.
Pina,	Retort silver.
Planilla,	Inclined platform to concentrate tailings.
Planillero,	Operator on *planilla.*
Plata,	Silver.
Plata cornea amarillia,	Iodyrite.
Plata cornea blanca,	Kerargyrite.
Plata cornea verde,	Embolite.
Plata mixta,	Alloy of gold and silver.
Plata negra,	Argentite.
Plata pasta,	The spongy bars of silver after retorting.
Plata piña,	Silver after retorting.
Plata verde,	Bromyrite.
Platillo,	Earthen plate for testing the slimes.
Plomo,	Galena.
Polvillo,	Rich black sulphurets left on *planilla.*
Polvo,	Fine grained amalgam from *cazo.*
Precipitado,	Metallic copper precipitated by iron or zinc.
Prueva en crudo,	An assay from the *cazo.*
Quebradero,	Breaker or crusher.
Quemadero,	Distillation furnace; retort.
Quemazon,	Black decomposed ore.
Quintal,	A hundred pounds.
Raspa,	That portion of the precious metals obtained by scraping the arrastra, or the patio.
Raspadura,	Scrapings.
Raspando,	Scraping; removing the amalgam from the arrastra by scraping.
Relaves,	Material remaining after the washing of the *tortas.* (See *polvillo.*)
Rendido,	Term applied to *torta,* when the amalgamation is concluded.
Repaso,	Treading of the ore in the *torta.*

Rosiclara,	Ruby silver.
Saltierra,	Impure salt from lagunes.
Solera,	Cast iron bottom of a Chilian mill.
Tahona,	A spoon arrastra.
Tahonero,	Man in charge of the *tahona* or *arrastra.*
Tanque,	First settling-tank.
Tentadura,	Assay.
Tierras de labores,	Smalls from the workings of the mine. (See *Metal granza de labores.*)
Tierras de llunque,	Smalls from the cleaners. (See *Metal granza de llunque.*)
Tina,	A circular tank; a round dolly-tub.
Tina cargadora,	Tank into which the slimes are first discharged.
Torta,	Heap of slimes on the *patio.*
Tosa,	Grinding-space in the *arrastra.*
Trapiche,	Chilian mill.
Trilla,	Heap of slimes on the *patio.* (See *Torta.*)
Voladora,	A muller.
Voltear la torta,	Spading: turning the *torta.*


TAHONA (Spoon Arrastre)
Scale 50:1
HALF SECTION ON A B.
HALF ELEVATION
HALF PLAN
CHIFLON (flume)
flume
A
B